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No. 1. — *Notes on the Geology of the Iron and Copper Districts of Lake Superior.* By M. E. Wadsworth.

There are probably no regions of like extent in the United States that have attracted greater interest or attention than the Copper and Iron districts of Lake Superior. The most discordant views have been held concerning their geology, and the origin of their ore deposits. There are also probably no districts in this country which have been more accurately studied, taking all of the conditions into consideration, than these were some thirty years ago. The geology, including the origin of their ore deposits, was then, for the time and methods of study, stated with a remarkable degree of accuracy, so far as it has been our province to observe or judge. It would not, then, be our duty to write concerning these districts, were it not that the almost universal belief of geologists at the present time regarding one, and in some respects the other district, is so entirely at variance with the facts as we interpret them. Before giving the facts it is necessary to present to the reader some of the various ideas held regarding the geology of both districts. We shall, however, in the main confine ourselves to those parts which we have visited, except so far as observations elsewhere have a bearing upon our work, or upon the questions which we wish to discuss.

It seems best to take up these views in chronological order, even if it does impart a dictionary flavor to this paper. First in order, then, we propose to discuss

The Iron District.

The earliest writer that it is necessary to quote here is Henry R. Schoolcraft, whose Narrative Journal of Travels, etc. was published at Albany in 1821. He speaks of the granite at Granite Point (p. 158), and of its being traversed by veins of greenstone trap. He gives the composition of the former rock, and advances his reasons for considering that it occupied its present position before the deposition of the overlying sandstone. He does not attempt to give the age of the sandstone, although he thinks "its position would indicate a near alliance to the 'old red sandstone.'"

Dr. Douglas Houghton, in his first Report on the Geology of Michigan, remarks upon the "appearance of primary and trap rocks forming mountain chains, and the great disturbance which has taken place since the deposition of the red sandstone," and says that this sandstone in the vicinity of Granite Point is "scarcely disturbed, resting upon nobs of primary rocks." * In Dr. Houghton's Fourth Annual Report, for 1841,† the rocks of this region are described as primary ones, consisting chiefly of granite, sienite, sienitic granites, and greenstone with metamorphic rocks on their flanks, forming a stratified series consisting of "talcose, mica and clay slates, slaty hornblende rock, and quartz rock; the latter rock constituting by far the largest proportion of the whole group." He considered that the granite passed "almost insensibly into a serpentine rock." (*l. c.*, p. 482.) In like manner, he thought that the granites on the southeasterly side of the district changed going northwesterly into a greenstone, and that the dikes traversing these granites were identical with the greenstone, having been injected into the granite. His serpentine bears a close resemblance to greenstone, and he states that "possibly a more close examination may show it to be a simple series of dikes, lying parallel to the line of cleavage of the slate rocks." (*l. c.*, p. 494.) Regarding Presque Isle he says: "This point of land has its origin from the simple elevation of a mass of trap rock, which rises on the north in abrupt cliffs, varying from twenty to sixty feet in height. The trap is mostly greenstone, though portions of it are so largely impregnated with a dark-colored, almost black serpentine, as to deserve the name of serpentine rock. The knob of trap under consideration is possessed of additional interest, from the unequivocal evidence of uplift, as also from the manner in which these evidences are exhibited. The cliffs of trap occupy the very extremity of the point, while the neck and central portions are made up of conglomerate or trap tuff and sand-rock, resting upon the trap. These upper rocks also appear upon the immediate coast, in cliffs of from twenty to sixty feet in height, and in many places they are seen resting directly upon the trap. The stratification of these sedimentary rocks has been very much disturbed, and they invariably dip, at a high angle, in all directions from the trap itself. The character of both rocks, at the immediate line of junction, is almost completely lost, and the evidences of change most unequivocally marked. But the most curious feature of the whole is, that the sedimentary rocks, for a distance of several hundred feet, have been completely shattered or broken into minute fragments, which, having retained their original position, were again cemented by the injection of calcareous matter. This injection has filled the most minute fissures, and so perfect is it, that, in looking upon the face of a mural cliff of these rocks, the veins may be easily seen at a distance of many rods, forming, as it were, a complete net-work over the cliff, and so minute is it, that a single hand specimen frequently contains many hundreds of these veins." (*l. c.*, p. 492.)

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* History of Michigan, by J. H. Lanman, (New York, 1839,) pp. 348, 352.

† Joint Documents, Michigan, 1841, pp. 471-607.

In this Report is the first mention of iron ore in this district that we have seen. He gives amongst the minerals of the "Metamorphic group of Rocks," "scaly red oxide of iron" and "hæmatite." Regarding the latter he says: "Although the hæmatite is abundantly disseminated through all the rocks of the metamorphic group, it does not appear in sufficient quantity, at any one point that has been examined, to be of practical importance." (*l. c.*, p. 504.)

In Dr. Houghton's Fifth Report some remarks were made both upon this district and upon the copper district, but nothing of special importance was added.* Mr. George N. Sanders, in a report to the Ordnance Office,† speaks of collecting "rich specimens of iron ore" on the Menomonee River. In the same documents for 1845 – 46 ‡ are given reports for the year 1845, by William A. Burt and Bela Hubbard.§ Mr. Hubbard evidently considered that the ridges in the Marquette Iron District were composed in the centre of eruptive rocks, but not outcropping, being "capped as well as flanked by the metamorphosed rocks." He states in regard to the metamorphic rocks that "these rocks are throughout pervaded by the argillaceous red and micaceous oxydes of iron, sometimes intimately disseminated, and sometimes in beds or veins. These are frequently of so great extent as almost to entitle them to be considered as *rocks*. The largest extent of iron ore noticed is in township 47 north, range 26 west, near the corners of sections 29, 30, 31, 32. There are here, too, large beds or hills of ore, made up almost entirely of granulated, magnetic, and specular iron, with small quantities of spathose and micaceous iron. The more northerly of these hills extends in a direction nearly east and west, for at least one fourth of a mile, and has a breadth little less than 1,000 feet, the whole of which forms a single mass of ore, with occasional thin strata of imperfect chert and jasper, and dips north 10 degrees, east about 30 degrees. At its southerly outcrop, the ore is exposed in a low cliff, above which the hill rises to the height of 20 or 30 feet above the country on the south. The ore here exhibits a stratified or laminated structure, and breaks readily into sub-rhomboidal fragments, in such a manner as will greatly facilitate the operation of quarrying or mining the ore. This bed of iron will compare favorably, both for extent and quality, with any known in our country." (p. 22.) The sandstone is said to be found frequently "surrounding, and in contact with, the uplifted masses of igneous rocks, and is then invariably much altered both in appearance and textures, and may, under such circumstances, fairly be considered as metamorphic." (p. 23.)

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* Joint Documents, Michigan, 1842, pp. 436 – 441.

† Senate Documents, 28th Cong. 2d Sess., 1844 – 45, XI., Doc. 175, p. 11.

‡ 29th Cong. 1st Sess., VII., Doc. 357.

§ See also Senate Documents, 1849 – 50, 31st Cong. 1st Sess., III. 802 – 842, and The Mineral Region of Lake Superior, by J. Houghton and T. W. Bristol, (Detroit, 1846,) pp. 3 – 39.

In the report of Mr. A. B. Gray to the Ordnance Bureau,* galena and copper pyrites were said to exist quite abundantly, and that it was probable that rich tin ores would be found. Mr. Samuel Peck is credited with having first explored the iron region, and called attention to the existence of that mineral (*l. c.*, pp. 15, 16).

Prof. H. D. Rogers † stated that the rocks in the vicinity of the Chocolate and Carp Rivers (Huronian of Brooks) were "the equivalents undoubtedly of the Primal sandstone and Primal slate," or the Potsdam sandstone of the New York survey.

Mr. William A. Burt, in his report "with reference to mines and minerals for 1846," ‡ (pp. 849 – 852,) described "fourteen beds of magnetic iron ore" in this district. Mr. Bela Hubbard in his report for the same year (*l. c.*, pp. 901 – 905) advances some views upon the passage of one rock into another, as follows: "A feature peculiar to all the rocks of the country alluded to as granitic, is their occasional trappose character, and the rare occurrence of mica. The constituents which make up the greater part are quartz, felspar, and hornblende; the proportions of which vary extremely. Thus, while the general character is that of true *sienite*, the absence of quartz in a distinct form often produces a *greenstone*, while frequently the last-mentioned mineral predominates almost exclusively, constituting a true *hornblende rock*, which is generally of a crystalline structure, and usually has a slaty cleavage. Again, quartz becomes the predominant mineral, constituting what may be denominated a *quartzite*. . . . . In a few instances talc was found to take the place of hornblende, constituting a *protogine*. . . . . We accordingly find the sienites assuming a trappose character, and often undergoing so insensibly the change from a granitic to trappean rock, that it is impossible to distinguish where one begins, and the other ends. In the operation of these changes, the excess of silica may be called in to account for the metamorphic rocks of the country, and particularly for the abundance of pure quartz in rocks and veins. . . . . Not only have changes accompanied the contact of trap with other rocks, such as have usually been referred to the heat of the injected mass when in a state of fusion, but equally marked changes have accompanied the conjunction of the *sienites* with the sandrock under circumstances where the same causes cannot be called in; for the latter gives evidence of having been deposited subsequently to the formation and uplift of the former, and the *sienite* was as often observed to have partaken of the change as the sedimentary rock. Without going further into detail of facts of merely scientific nature, it may be sufficient to say that it seems more reasonable to attribute the metamorphism which has taken place in both rocks rather to galvanic and chemical action than to igneous causes, which are so generally called in to account for all these phenomena. The rocks designated upon the maps as metamorphic, occupy, as it were, beds amid the surrounding primary rocks; and while we would avoid any theoretic conclusions as to their origin, it may be stated that, throughout the whole primary region, the limits of each rock, except in the case of dikes, are seldom distinctly defined, but one passes into the other by gradual transition; so that often rocks of distinct name and character can be considered only as members of the same formation, the constituents of which have become differently aggregated."

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* Executive Documents, 29th Cong. 1st Sess., Vol. VII., No. 211, 1845 – 46, pp. 2 – 23. Am. Jour. Sci., (2,) Vol. V., 1848, p. 151.

† Proc. Bost. Soc. Nat. Hist., April 1st, 1846, II. 125.

‡ Senate Documents, 31st Cong. 1st Sess., 1849 – 50, III. 371 – 935.

Mr. J. W. Foster, in his report to Dr. Charles T. Jackson, dated September 28, 1848,* describes part of the iron region. The rocks are considered to be older than the sandstone, which is regarded as belonging to the oldest palæozoic rocks. Previous to this, Dr. John Locke attempted to describe the district in part; but his account appears to be of no value, except from an historical point of view.† We would, however, call attention to his bathetic description of the "Pictured Rocks" (pp. 189–191).

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* Senate Documents, 2d Sess. 30th Cong., 1848–49, III., Doc. 2, pp. 159–163; Executive Documents, III., Doc. 12, pp. 159–163.

† Senate Documents, 1st Sess. 30th Cong., 1847–48, II. 186–189, Oct. 25, 1847.

Pages 371 – 801 of a publication previously mentioned* is devoted to the publication of the reports of Dr. C. T. Jackson and his corps. This document is one of the curiosities of geological literature, — a *rara avis.* It was printed in such a manner that in many cases it would be very difficult, if not impossible, to determine who were the authors of the different parts of the text, were it not for the fusillade all along the line.

Dr. Jackson gives (pp. 477 – 479) some account of his first knowledge of the iron ore (1844) in this district, but it seems that he never visited the region himself. Dr. John Locke, in his field-notes for 1847 (*l. c.*, pp. 572 – 605), describes the rock of Presque Isle as "a light-green trap, reticulated with white veins near the junction of the sandstone, with which the trap is apparently interfused." He also describes the iron region to some extent. He considers that the trap rocks are frequently interfused with the metamorphic ones in the district, and states that certain quartz veins "deserve close examination for gold, silver, and other rare metals. Veins of this description, if they prove important, can undoubtedly be found in the metamorphic rocks."

It is well known that the early explorers had to contend with very great difficulties in their work in this region; but probably none ever suffered such aggravation of spirit as did Dr. Locke, when, on July 27, 1847, his compass ran wild and its poles stood seventeen feet and eight inches apart, unless it was when he found his provisions were only a few sticks of wood and a bucket of bean soup.† Mr. J. W. Foster, in his report to Dr. Jackson, dated May 26, 1849 (*l. c.*, pp. 773 – 785), gives a description of the iron region, as studied by him in 1848. He regards the iron ores as sedimentary deposits. "These beds, so far as I have observed, present a marked similarity in mineralogical characters, and derive their origin from common causes, and those were *aqueous.* The jointed structure and waved stratification of some of the beds prove that *igneous* causes have operated, since their deposite, to modify and change their character." (p. 776.) "Here, they certainly bear upon their surfaces strong marks of their mechanical origin. They are regularly stratified, and often contain thin seams of silex in minute grains, so that a specimen, on its cross fracture, resembles ribbon-jasper. The lines of stratification can readily be distinguished from those of lamination. Like the slates, they are often found contorted and wrinkled, and the same facts could be adduced in both cases to prove their common origin." (p. 779.) This description belongs, for the most part, to the

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* Senate Documents, 1st Sess. 31st Cong., 1849 – 50, III. 371 – 935.

† Senate Documents, 1st Sess. 30th Cong., 1847 – 48, II., Doc. 2, p. 190.

Menomonee region, but part of the Marquette district is included. The granites were classed by him as igneous rocks.

Printed in the midst of these reports is one from Messrs. Foster and Whitney (*l. c.*, pp. 605 – 626) made to the Land Office and Interior Department, dated November 5, 1849, which gives some account of the Iron and Copper districts. The iron is stated to occur in the metamorphic formation. "This formation consists of hornblende, talcose, and chlorite slates, with associated beds of hornblende and felspar rocks, evidently trappean in their origin." (pp. 609, 610.)

December 19, 1849, Professor J. D. Whitney gave some account of this region before the Boston Society of Natural History.* The iron ore was then stated to be of igneous origin. In a report transmitted to the Interior Department, October 25, 1850,† Messrs. Foster and Whitney state that the sandstone is of Potsdam age. "Below the whole of the silurian rocks we meet with a class of deposites which were probably detrital in their origin, but which have been so metamorphosed as essentially to change their structure. They are destitute of organic remains, and contain imperfect traces of stratification. They consist of various schists and beds of quartz, marble, and specular and magnetic oxide of iron. We have termed these various groups the *azoic system*, — a system which, thus far, has not been fully recognized in Europe, but the existence of which the results of this survey, as well as that of Canada under Mr. Logan, have fully demonstrated. Upon the upturned edges of these slates the Potsdam sandstone is found reposing in a nearly horizontal position. They form the nucleus around which the newer rocks have been deposited, and are extensively developed between the shores of the two lakes. They are the depositories of the most extensive beds of iron known in the world."‡ The term "Laurentian" was first proposed by Sir William E. Logan, in 1853,§ for the metamorphic rocks underlying the Potsdam sandstone north of the St. Lawrence, although it had been used some years before by Mr. Edward Desor to designate certain drift deposits in the St. Lawrence valley, and by the law of priority the name should have been retained in its original sense.

May 5, 1851, a paper was presented to the American Association ||

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* Proceedings, III. 210 – 212.

† Senate Documents, 2d Sess. 31st Cong., 1850 – 51, II., Doc. 2, pp. 147 – 152.

‡ See also Bull. Soc. Geol. France, 1850 – 51, (2,) VIII. 89 – 100.

§ Report of Progress Geol. Survey of Canada, 1852 – 53, p. 8.

|| Proceedings, V. 4 – 7.

by Messrs. Foster and Whitney, entitled, "On the Azoic System, as developed in the Lake Superior Land District," in which the distribution of the azoic rocks in North America was briefly pointed out. The term Azoic was adopted by them from Murchison and De Verneuil,* but limited in its signification by Foster and Whitney "to a class of rocks supposed to be detrital in their origin, and to have been formed before the dawn of animal or vegetable life. It comprises the most ancient of the strata which form the crust of the earth, and occupies a distinct position in the geological column; being below the Potsdam sandstone. In this district, the rocks consist, for the most part, of gneiss, hornblende, chlorite, talcose, and argillaceous slates; interstratified with beds of quartz, saccharoidal marble, and immense deposits of specular and magnetic oxide of iron. Most of these rocks appear to be of detrital origin, but to have been greatly transformed by long-continued exposure to heat. They are sub-crystalline, or compact, in their texture, and rarely present unequivocal signs of stratification. They have been subject to the most violent dislocations. In one place, the beds are vertical; in another, reversed; and in another, present a series of folded axes. Intermingled with them is a class of rocks whose igneous origin can hardly be doubted, and to whose presence the metamorphism so characteristic of this series is, in a measure, to be ascribed. They consist of various proportions of hornblende and feldspar, forming traps and basalts; or, where magnesia abounds, pass into serpentine rocks. They appear, in some instances, to have been protruded through the pre-existing strata, in the form of dikes or elvans; in others, to have flowed in broad lava streams over the ancient surface; and in others, to have risen up through some wide-expanding fissure, forming axes of elevation." Gaseous sublimations, intense pressure, and electro-chemical agencies were thought to have assisted in the metamorphism, as well as the plutonic masses. "Since the theory of metamorphism has been generally adopted, many of the rocks which were formerly regarded as igneous are now referred to aqueous agency, and their transformations traced to the presence of erupted rocks. They here cited numerous examples of metamorphism, showing that argillaceous schist is transformed into gneiss; sandstone into compact vitreous quartz; and limestone into saccharoidal marble, when brought in contact with eruptive masses. They therefore inferred, that these obscurely bedded rocks, — such as gneiss, and the crystalline schists, — were of sedimentary origin; that no rock was to be regarded as igneous, unless it occur in vast, irregular masses, like granite; in dome-shaped, or crater-like summits, as basalt, or trachyte; in long lines, as dykes or elvans cutting through the incumbent strata; in ramifying veins, like granite; or broad lava sheets, like trap. Many eminent geologists maintain that the lowest stratified rocks are but portions of the Silurian System, and that, from long-continued exposure to heat, the lines of stratification have become obscure, and all traces of organic remains obliterated. Our observations in this district (they remarked) have led us to a different conclusion."

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* Russia and the Ural Mountains, I. 10.

"The evidence is ample that the base of the Silurian System reposes upon their upturned edges, and that the causes by which the metamorphism of the former was effected had ceased to operate before the deposition of the latter. Between the two systems there is a clear and well-defined line of demarkation. It forms one of those great epochs in the history of the earth, where the geologist can pause, and satisfy himself of the correctness of his conclusions. On the one hand he sees evidence of intense and long-continued igneous agency, and, on the other, of comparative tranquillity and repose. . . . . The Azoic Series was characterized by immense deposits of specular and magnetic oxide of iron. This might, with great propriety, be denominated the IRON AGE of Geology. . . . . It was evident that these strata were everywhere plicated and folded, and that the observer passed over a repetition of beds, instead of a succession of beds; but that the strata, throughout the whole region, had been so shattered by earthquakes, and so metamorphosed, by direct or transmitted heat, that it was impossible to identify them, except over limited areas." Later, attention was called to the point that this continent was as old as the European, if not older.* The above points were given in much greater detail in Messrs. Foster and Whitney's "Report on the Geology of the Lake Superior Land District. Part II. The Iron Region, together with the General Geology." Transmitted November 12, 1851.† Such portions of this report as it is necessary to note will be touched upon below.

The range of quartzose hills extending from Carp River by Teal Lake was described to some extent, and was regarded as formed from a metamorphosed sandstone. Enclosed fragments of jasper and slate, lines of bedding, and obscure traces of ripple-marks were said to have been seen in this quartzite (*l. c.*, pp. 15, 16). Of Presque Isle they said: "The outline of this mass is very irregular, and resembles an immense consolidated lava-stream, except that the vesicular structure is wanting. To the north, the surface of the igneous rock is bare; but, on the eastern side, it is covered in places with a rudely stratified mass, which appears to have been deposited in the inequalities of the pre-existing surface. It resembles a volcanic sand, or ash, portions of it being composed of a scoriaceous mass of a light-brown color, and reticulated with numerous veins of a white mineral, portions of which are calcareous, and others silicious." (*l. c.*, pp. 121, 122; see, also, pp. 18 and 92.)

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* Same Proceedings, page 151. See also entire article, pp. 136 – 151.

† Senate Documents, Spec. Sess. 32d Cong., III., 1851.

This rock was thought to be of prior origin to the sandstone. The sandstone was regarded as Potsdam, and as the same rock as that on Keweenaw Point. It was pointed out that this sandstone rests nearly horizontally on the water-worn edges of the nearly vertical quartzite. (*l. c.*, pp. 122, 123.) The iron ores were regarded as of igneous origin, forming intrusive masses and overflows, principally the latter, like a lava, but consolidated under pressure of a deep ocean. Sublimations of the iron occurred while the denudation and deposition of the eruptive masses that were by the shore-line aided in making the different formations. After this series of igneous and aqueous ore-beds were laid down, "the whole series of beds, slaty, quartzose, ferruginous and trappean, were elevated, and, in all probability, folded, perhaps at the epoch of the elevation of the granite ranges on the north and south of the ferriferous belt of the azoic system." (*l. c.*, pp. 50-69.)*

Dr. J. J. Bigsby regarded the granite as igneous, and taught that the metamorphic rocks had been "upheaved and altered by the intrusion of igneous rocks in instances innumerable."† Professor Whitney, in his "Metallic Wealth of the United States," (Philadelphia, 1854,) again advocated the igneous origin of the iron ores in this district, as well as in some other localities.‡

In 1854 there was published by Henry R. Schoolcraft, in Philadelphia, a work entitled "Summary Narrative of an Exploratory Expedition to the Sources of the Mississippi River, in 1820: resumed and completed by the Discovery of its Origin in Itasca Lake, in 1832. By Authority of the United States. With Appendices, comprising the Original Report on the Copper Mines of Lake Superior, and Observations on the Geology of the Lake Basins and the Summit of the Mississippi; together with all the Official Reports and Scientific Papers of both Expeditions." As giving us an insight into the early knowledge of the geology of the southern shore of Lake Superior, this work naturally should be of great value, especially as it purports to contain the original scientific reports. In the Preface we learn that he brings the subject down to the date of publication in some respects, and by comparing the work with the original, published in 1821, we find that he gives discoveries as if made by himself in 1820 which were not made until at least nearly twenty-five years later. This insertion in the body of the text may perhaps be pardoned, in the light of the Preface; but when it comes to publishing official documents with their original date and official signature, but with a "tinkered" body, we object. We cannot therefore credit Mr. Schoolcraft with the discovery of the iron ore of the Marquette district in 1820, although any one reading this work would suppose that he discovered it. It represents to us simply what he wished, in 1854, others should think he had known and written in 1820. This also applies in part to his reports on the Copper district, and we shall not mention the book further.

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* Am. Jour. Sci., (2,) XVII. 11-38, 1854; XXII. 305-314.

† Edinburgh New Phil. Jour., 1852, LIII. 55-62.

‡ Pp. 37, 429-437, 477, 478. See also Proc. Am. Assoc. Adv. Sci., 1855, 209-216; Mining Magazine, (New York, 1856,) VII. 67-73; Am. Jour. Sci., (2,) 1856, XXII. 38-44.

In 1854 was also published a description of this and the Copper region by Fr. C. L. Koch.* The trap and granite were regarded as eruptive, and it was thought that the quartz rock (quartzite) may probably be so. The schists are supposed to have been metamorphosed through the agency of igneous masses. The iron rocks he would consider as upheaved from great depths, or else to have suffered great metamorphism by the influence of igneous masses. That they (the iron rocks) may be simply the quartz rock impregnated with oxide of iron is thought probable.

In 1855 and 1856 two papers on this and the Copper district were published by Prof. L. E. Rivot.† As we understand his work, it would seem that he regarded all the rocks from Sault St. Marie to the Ontonagon River as of sedimentary origin, and of the same geological age, whose differences were entirely owing to peculiar metamorphism, or its absence, as the case might be. The sandstones were in general, in the Marquette district, of prior deposition to the other rocks in the places in which they are now to be found. The traps and their associated schists, which originally formed the base of the sandstone, had been locally changed and pushed up, dislocating the surrounding sandstones. The granites and sienites were regarded as probably the products of the last stage of metamorphism, although they were eruptive in their present position. The "diorites" of the Marquette district were considered to be the same, in age and general characters, as the traps in the Copper district, all being interstratified with the sedimentary rocks with which they are associated, and into which they gradually pass. The differences between them and their associated rocks were owing to the degree and manner of the metamorphism. The whole formation from the Sault to the Ontonagon was regarded as Potsdam, being overlaid by the magnesian limestone.

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* Studien des Gott. Vereins Bergm. Freunde, VI. 1-248.

† Annales des Mines, (5,) VII. 173-328, X. 365-474.

Prof. J. P. Lesley, in his "Iron Manufacturers' Guide," (New York, 1859,) opposes the view of Professor Whitney, that the iron ores of Lake Superior or of any other region are eruptive. It seems strange that a geologist and mining engineer of his reputation should fall into the errors that he has, in interpreting the latter's work. After quoting Professor Whitney's remarks on *mineral veins*, he says: "The first theory which Mr. Whitney so summarily dismisses as opposed to all known facts, is in certain principal localities the only one which apparently embraces all the facts. The so-called *veins* of specular and magnetic ore in Northern New York, New Jersey, and Missouri are of this class, and when Mr. Whitney says that 'the mountain masses of Missouri have pre-eminently an eruptive character, and are associated with rocks which have always been considered as of unmistakably eruptive origin,' we must interpret the expression by the preceding and succeeding paragraphs as the judgment of the past, and not his own, saying that the specular and magnetic ores of Lake Superior, New York, and Scandinavia fall into the same category, and yet are not true veins, but 'slaty beds impregnated with peroxide of iron, ... exhibiting the appearance of a secondary action having taken place since their original formation.'" (*l. c.*, pp. 354, 355.)

On referring to Professor Whitney's work, it can be readily seen that the remarks on *mineral veins* by Professor Whitney have nothing whatsoever to do with the above quoted iron-ore deposits, which are not *mineral veins* in any sense, and were distinctly separated from them by him. The expression, "slaty beds, impregnated with peroxide of iron," was used in reference to the mine of Hessel, Norway, while the statement, "exhibiting the appearance of a secondary action having taken place since their original formation," was applied to the azoic ores of New York, and is copied by Professor Lesley on page 357 of his work in its proper connection. It will thus be seen that specials have been transformed by Professor Lesley into generals, entirely out of their original use; and remarks about one thing are said to have been made about another.

After copying several pages from Professor Whitney's "Metallic Wealth," he writes: "It appears from the foregoing that Mr. Whitney accepts both the eruptive and the sedimentary theories of the formation of the primary iron ores, and applies the former to unknown, invisible masses, antecedent to and now deeply buried under all, even the oldest rocks which appear upon the present surface; masses of far greater size and depth than the greatest yet discovered, proportionate to the greater scale of all volcanic action in that pre-azoic day, and offering their sides and tops to such erosion and solution as would of course happen in such unsettled times, and be sufficient for producing the vast sediments of iron which have been taken for volcanic outbursts of the molten metal. But there is a fatal difficulty in the way of this hypothesis. These ore-beds are not *breccias*. Deposits of the kind imagined would be *conglomeritic;* blocks of pig-iron would be seen scattered through strata of granite." Here, again, he has entirely misunderstood Professor Whitney's views, which were that the great masses of ore in the Lake Superior district were eruptive where they now are, and were never sedimentary deposits, while associated with and derived from them are the *brecciated* and *conglomeritic* ores, as well as other sedimentary beds. If it is necessary, the "pig-iron" can doubtless be found at Ovifak, Disko, in the basalt (*l. c.*, pp. 333 – 335, 353 – 361, 480 – 489).

In 1861 the rocks of the Marquette iron district were referred to the Huronian system by Dr. T. Sterry Hunt, on the authority of Mr. Alexander Murray.* Dr. Hunt regarded the Huronian then as the equivalent of the Cambrian of the European geologists.

Dr. Dana† states concerning the iron ore of Michigan and elsewhere: "Their alternation with chloritic and other schists and gneissoid rocks shows that they are metamorphic as well as the schists." The same statement is made in the edition of 1874 (p. 74), and doubt is expressed as to whether they belong to the Laurentian or Huronian (pp. 151, 152, 159, 160). Since the above was written the third edition of the Manual has been published, but this affirms as strongly as ever that the iron ore is in stratified sedimentary beds, and that it is distinctly interstratified with the schists.

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* Am. Jour. Sci., 1861, (2,) XXXI. 392 – 414; Canadian Nat. and Geol., 1861, VI. 81 – 105, VII. 127.

† Manual of Geology, 1862, pp. 83, 84.

Later, Dr. J. J. Bigsby, while considering the Huronian as distinct from the Cambrian, still referred the rocks of this district to the Huronian.*

In the "Geology of Canada," 1863, these rocks are taken as Huronian (p. 66). The rock at Presque Isle was classed as a sedimentary serpentine belonging to this formation by Dr. Hunt (pp. 472, 595); taking his analysis from Professor Whitney's work,† who regarded it as closely related to serpentine.

Dr. Hunt states also that the great beds of red hematite are stratified (p. 596), and he considers their deposition as proof of the presence of vast amounts of organic matter at that day (p. 573).

Dr. J. P. Kimball, under date of December 19, 1864,‡ remarks: "My own observations in the Iron region impressing me with the indigenous character of the larger masses of diorite and granite represented within the defined area of the metamorphic strata, and their entire distinctness from intrusive dikes or erupted masses, and concurring in the recognition of these strata by Mr. Murray as Huronian, I am disposed to regard the entire region as of metamorphic character, all of whose larger masses of crystalline rocks are indigenous, and to be divisible into the two formations, Laurentian and Huronian: the former formation probably forming the surface of the areas known as the granite ranges, while the latter probably occupies, with minor deviations, the limits laid down for the crystalline schists comprehended under the name Azoic." (*l. c.*, p. 293.) "Possessing the same stratigraphical conditions as the schistose rocks, while many varieties of them are represented in the schists by their exact counterpart as to composition, the crystalline Huronian rocks must be regarded as essentially metamorphic, while in a comprehensive view of the whole series it is seen that together with variable conditions of deposit, it indicates variable degrees of local metamorphism. Plentiful evidence exists of the blending of a rock of one character into that of the other, or the continuity between crystallized and schistose beds. . . . . Besides the indigenous crystalline rocks distributed throughout the Huronian series, exotic or intrusive crystalline rocks are met with, but only in the form of dikes, and limited to a narrow distribution." (*l. c.*, p. 295.) "It may not be inappropriate to suggest the probability that the larger and more persistent bodies of greenstone bearing approximately east and west — that is, conformably with the axes of the folds which constitute a regular system of flexures coextensive with the distribution of the Huronian series in the vicinity of Marquette, are, in reality, indigenous greenstone, and a portion of the development of the diorite upon which repose the upper members of the series, and which, as will hereafter be shown, is uncovered along most of the ridges of the region." (*l. c.*, p. 296.) "The position of the beds of specular iron ore has already been stated to be at the top of the Huronian series, ... interstratified with talcose and argillaceous schists. Sharing the plications of the entire series, these specular schists, as they may properly be called, are accordingly folded into synclinal basins and anticlinal crests." (*l. c.*, p. 299.) "It has been shown that the iron ores of the Huronian series in Michigan are essentially schists and heavy-bedded strata, in which none of the phenomena of aqueous deposits formed by precipitation from water on the one hand, or by detrital accumulation on the other, are wanting. They exhibit not only stratification, anticlinal and synclinal folds, but are invariably traversed by systems of joints, and at many points exhibit a perfect slaty cleavage. The intimate connection between the greenstones, hornblende rocks, and aluminous and magnesian silicated schists of the ferriferous series, has already been indicated in general terms, these rocks not only alternating with, but passing into each other." (*l. c.*, p. 302.) "Chemical reactions in crystalline sediments resulting from the disintegration of crystalline silicated rocks, and operated upon by carbonated waters, are amply capable to have produced the lithological conditions of augitic rocks, clay-slates, schalstone, and other schists, together with the oxidized ores of iron intercalated with greenstone among the ancient crystalline rocks of North America as well as of Europe. . . . . From a stratigraphical point of view, while evidence is elsewhere often obscure, the Huronian greenstone, schists, and iron ores of Northern Michigan, in the absence of close attention to their special chemical conditions, exhibit sedimentary and metamorphic phenomena adequate to render quite untenable, it is believed, the theory of the exotic character of any portion of them." (*l. c.*, p. 303.) The granite is also regarded as indigenous by Dr. Kimball.

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* Quart. Jour. Geol. Soc., 1863, XIX. 36 – 52.

† Am. Jour. Sci., (2,) XXVIII. 18, 1859.

‡ Am. Jour. Sci., (2,) 1865, XXIX., 290 – 303.

Mr. J. W. Foster, in 1865,* states: "The Iron Region consists of an assemblage of rocks of various kinds, such as argillite, talcose, chlorite, and hornblende schists, quartzites, and occasionally dolomites, all of which are supposed to be of metamorphic origin, intermingled with rocks whose igneous origin can hardly be doubted, consisting of the various compounds of feldspar and hornblende, forming greenstone or dolorite; or where silica abounds, forming syenite; or serpentine where magnesia is in excess. . . . . It may be stated as a general rule, that the great iron deposits of the district occur in close proximity to the igneous rocks, mainly greenstone. This rock forms nearly all of the prominent peaks of the region, not in continuous ranges, but in a succession of dome-shaped knobs, while the iron ores repose upon their sides, or dip beneath their bases, so that the greenstone appears rather in the form of intercalated beds than as wedge-shaped masses. The whole region has been subjected to a powerful denudation, and the greenstone, being the more unyielding rock, has been left in the form of knobs, or of ill-defined ridges. I cannot recall an instance where it forms a true axis of elevation." (*l. c.*, p. 9.) The limonitic ores (soft hematites of the miners) are regarded by him and by Dr. Kimball as formed by the decomposition of the hematite ores *in situ* (*l. c.*, pp. 24, 81). Dr. Kimball also states in this report (p. 87): "Regarding the bodies of specular iron ores and earthy red hæmatites of the Marquette Region as of combined aqueous and metamorphic origin; and, conditional to this view, apprehending the stratigraphic arrangement of the general system of aluminous and magnesian silicated schists, among which these beds are intercalated, generally regular and constant as it is, the topography of the country affords tangible data for tracing the hidden conditions of ore beds, and their relation to outcropping rocks. The region is traversed by a series of folds, or undulations, of the entire series of rocks, which impart to the surface its contour, modified only through subsequent agencies of denudation. Thus the crests of the undulations (*i. e.* the ridges and hills), originally overlaid by beds of iron ore, which in its purer conditions readily yielded to the abrasion of glacial action, were worn down and commonly stripped to the underlying rock."

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* Geology and Metallurgy of the Iron Ores of Lake Superior, by J. W. Foster and J. P. Kimball, New York.

In "Coal, Iron, and Oil, or the Practical American Miner," etc., by S. H. Daddow and Benjamin Bannan, published in 1866, a decidedly original view of the origin of the iron ores and their associated rocks, as well as of the placer gold of California, is given (pp. 532, 533, 546 – 550). All are thought to have been formed by volcanic action. "We are aware that all our sedimentary rocks were formed in water, and that the materials forming them are the results of volcanic action. The logical sequence is, that those volcanoes either existed in water, or vented their lava into it. Metals are always heavier than their matrix, or the earthy strata in which they are found; thus, if the lava contained a large amount of metal, it would be the first to be precipitated to the bottom of the water into which the lava was vented. The lava would not run in a solid stream from the crater, and solidify as a stratum in the water, but the moment it touched the adverse element it would be shivered to atoms, and thrown back into the atmosphere with the steam it would create, and the lighter portions would naturally arise in dust and ashes, and be carried by winds and waves and tides to remote localities, while the heavier materials would be precipitated in the vicinity in the order of their density. . . . . We may refer most of our great Azoic beds of magnetic and specular ores and red oxides of iron to this cause, and their formation to these agencies. We may also refer the alluvial or drift gold in the 'placers' of California and the 'diggings' of Australia to the same causes." (*l. c.*, p. 533.)

It is such theories as this, and many others touched upon in this paper, that give the "funny side" to our work, and serve to enliven the tedium of it; otherwise they would not be worthy of preservation. They stand as the caricatures of science, although they were evidently sober realities to their authors.

A series of papers was published by Dr. Hermann Credner in 1868–70, the titles of which will be given in the literature at the end of this work. He divides the formations as follows: the gneiss-granite, or Laurentian formation, and the limestone-quartzite-iron-stone, or Huronian formation. The latter is said to unconformably overlie the former, but the evidence, so far as given, is derived from the dip and strike of the lamination, and not from observation of the kind and manner of their contact. The diorites, iron ores, and all their associated rocks, except a few, are regarded as interbedded formations. The iron ore is supposed to have all originally been magnetite, and in part changed since to hematite and limonite. Near Marquette certain diorites were seen by him to be eruptive; therefore they were taken to be of different age from the interbedded diorites associated with the iron ore, and younger than the Huronian.

In Prof. A. Winchell's Report of Progress of the Geological Survey for 1870 we find the following remark: "The rich masses of magnetic and hematitic ores of iron are found not to be those erupted outbursts which the older geologists were inclined to regard them. They are simply constituents of the system of sedimentary deposits which make up the Huronian System of Michigan. The diorites of the region appear to be equally of sedimentary origin, and are found strictly interstratified with chloritic, siliceous, talcose, argillaceous, micaceous, and hematitic schists, in the foldings and convolutions to which these masses of ancient strata have been subjected." (*l. c.*, pp. 26, 27.)

In 1873 the Report of Major T. B. Brooks on the Iron districts of Michigan was published, with various accompanying documents by Messrs. Julien, Wright, Houghton, Lawton, and others.* Mr. Brooks refers the date of the discovery of the iron ore to 1844, by Mr. William A. Burt and party, but the first official documents giving an account of the ore seem to have been the reports of Burt and Hubbard for 1845,† referred to in the early portion of this paper. Besides the sandstone, the formations of this district are divided by Mr. Brooks as follows: "*The Iron-bearing Rocks*, corresponding, it is assumed, with the Huronian system of Canada, consist of a series of extensively folded beds of diorite, quartzite, chloritic schists, clay, and mica slates, and graphitic shales, among which are intercalated extensive beds of several varieties of iron ore. . . . . *The Granitic Rocks*, which so far have produced no useful minerals, and which are believed to be the equivalents of the Laurentian of Canada." (*l. c.*, p. 66.)

As we shall have largely to deal with Mr. Brooks's work hereafter, we shall quote quite fully from it. "Useful minerals which occur in beds, like the iron ores of Lake Superior, will usually be overlaid and underlaid by rocks having different characters, and which maintain those characters for considerable distances. Next to finding the ore itself, it is desirable to find the hanging or footwall rock. Whoever identifies the upper quartzite in the Marquette region, or the upper marble in the Menominee region, has a sure key to the discovery of any ore that may exist in the vicinity. With few exceptions, all the rocks in the region we are describing are stratified,—that is, arranged in more or less regular beds or layers, which are sometimes horizontal, but usually highly inclined. This stratification, or *bedding*, is generally indicated by a difference in color of the several layers, oftentimes by a difference in the material itself, but occasionally the only difference is in the texture or size and arrangement of the minerals making up the rock. . . . . In general, a *striped rock*, whether the stripes be broad or narrow, plain or obscure, on fresh fracture or weathered surface, is a stratified rock."

We would invite Mr. Brooks to inspect the volcanic rhyolites, many of the felsites that are known to be eruptive, as well as many of the furnace slags to be seen in the Marquette district. "Sometimes the power which produced the *folds* seemed greater than the rocks could bear, and cracks or breaks, and *faults* or throws, are the result, though these are not numerous in the Lake Superior region. Cracks so produced, and filled with material other than that constituting the adjacent rocks, are called *dykes;* or, if the material be crystalline and metalliferous, *veins*. As iron ore in workable quantities does not occur in this form in this region, vein phenomena will not be considered here." Of the Huronian series "the prevailing rock is a greenstone, or diorite, in which, like the copper traps, the bedding is usually obscure; but the intercalated schists and slates, which usually bear strong marks of stratification, make it usually not difficult to determine the dip of the beds at any point. . . . Descending to the oldest or bottom rocks of the Lake Superior country, the granites and associated beds (*Laurentian*), we find the bedding indications still more obscure, and often entirely wanting." (*l. c.*, pp. 74, 75, 76.)

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* Geological Survey of Michigan, I. 1–319; II. 298 pp.

† I. 13, 14; II. 235–238.

"In subdividing the Huronian or iron-bearing series which we have particularly to study, the rocks have been grouped (1) *lithologically*, *i. e.*, according to their mineral composition, and (2) *stratigraphically*, *i. e.*, according to relative age. As this system was first described and named by the Canadian geologists, their names have been employed as far as possible in the body of this report; the identity in composition of many of our rocks with theirs, having been established by an examination of a large number of Marquette specimens by Dr. T. Sterry Hunt." (*l. c.*, p. 82.) "The several beds or layers of the Huronian system, as developed in the Marquette region, are numbered upwards from I. to XIX. . . . . I., II., III., IV., are composed of beds of siliceous ferruginous schist, alternating with chloritic schists and diorites, the relations of which have not been fully made out; V. is a quartzite, sometimes containing marble and beds of argillite and novaculite; VI., VIII. and X. are siliceous ferruginous schists; VII., IX. and XI. are dioritic rocks, varying much in character; XIII. is the bed which contains all the rich specular and magnetic ore, associated with mixed ore and magnesian schist; XIV. is a quartzite, often conglomeritic; XV. is argillite or clay slate; XVI. is uncertain, it contains some soft hematite; XVII. is anthophyllitic schist, containing iron and manganese; XVIII. is doubtful; XIX. is mica schist, containing staurolite, andalusite, and garnets. This classification, it will be borne in mind, applies only to the Marquette region. . . . . These beds appear to be metamorphosed sedimentary strata, having many folds or corrugations, thereby forming in the Marquette region an irregular trough or basin. . . . . While some of the beds present lithological characters so constant, that they can be identified wherever seen, others undergo great changes. Marble passes into quartzite, which in turn graduates into novaculite; diorites, almost porphyritic, are the equivalents of soft magnesian schists." (*l. c.*, pp. 83, 84.)

The "soft hematites" are thought to result, perhaps, from the decomposition of a "limonitic siliceous schist," with which they are associated. "It is not at all improbable that this change may have been brought about by the alkaline waters of former thermal springs." (*l. c.*, pp. 90, 91.)

The "diorites" are said to graduate from a heavy, tough, black variety into a soft, light-colored rock, resembling chloritic schist more than anything else, and called by him dioritic schist. "The bedding of these rocks is generally obscure, and in the granular varieties entirely wanting. It is usually only after a full study of the rock in mass, and after its relations with the under and overlaying beds are fully made out, that one becomes convinced, whatever its origin, it presents in mass precisely the same phenomenon, as regards stratification, as do the accompanying schists and quartzites. . . . . No reference is here made to the false stratification or joints, which are numerous and interesting, but which unfortunately, for want of space, can receive no other attention here than to warn the observer against mistaking *joint* planes for *bedding* planes, which is sometimos done, even by experienced observers." (*l. c.*, pp. 102, 103.) He also states that in no case has he abserved a Huronian diorite in the Marquette district that does not conform "with the schistose and slaty strata with which they are associated." (*l. c.*, p. 156.)

The rocks associated with the hard ores and "diorites" are called "magnesian schists (mostly chloritic)." He says regarding them: "It would be difficult for a skilled lithologist, and impossible for me, to draw the line between the chloritic schists here considered and the dioritic schists." Regarding the chloritic schist at one locality associated with "specular slate ore," it is stated: "Prof. Pumpelly has suggested that one may be a pseudomorph after the other. In this connection it may be remarked that no gradual transition of one into the other was observed, the division planes being in each instance sharply defined." (*l. c.*, pp. 104, 105.)

Regarding the connections of the ore in the Barnum mine with that in the Lake Superior mine, he writes: "It shows that such formations are not vein or dyke-line deposits, but true stratified beds, like the rocks by which they are enclosed. Their structure is therefore essentially the same as the coal, limestone, sandstone, and slate-beds, which are regarded as sedimentary deposits from water, subsequently more or less altered by heat, pressure, and chemical waters acting during immense periods of time. The Lake Superior-Barnum deposit evidently has a *bottom*, which will be reached within a period, of which it is worth while for the present generation to take some heed. . . . . The time may come when, having worked out the steep, upturned edges of the basins, and the flatter or deeper portions of the deposit are reached, ore properties will be valued somewhat according to the number of acres *underlaid by ore*, as coal now is. Passing to the east portion of the Lake Superior mine, I confess myself unable to give any intelligent hypothesis of its structure. . . . . There seems to have been such a gathering together, crumpling, squeezing, and breaking of the strata, as nearly to obliterate the stratification. . . . . The remarkable features are the great masses of light grayish-green chloritic schist, having a vertical east and west cleavage, no discernible bedding planes, and holding small lenticular masses of specular ore, which conform in their strike and dip with this cleavage, and which seem to have no structural connection with the main deposits. They appear like dykes of ore, squeezed out of the parent mass, which we may suppose to have been in a comparatively plastic state when the folding took place; or they may have been small beds, contained originally in the chloritic schist, and brought to their present form and position by the same causes, which produce the cleavage in the schist. . . . . The peculiar nature of the hanging wall of the Lake Superior mine deserves further notice. Instead of the quartzite, which we have hitherto found overlying all the deposits of rich ore, we have here a magnesian schist very similar to, if not identical with, that already mentioned as being associated with the ore." (*l. c.*, pp. 138 – 140.)

"All the Huronian rocks north, east, and south from the Jackson mine are below, or *older than the ore formation* (XIII)., and all the rocks to the westward and inside of the ore-basin are *younger*, hence above it." (*l. c.*, p. 143.) "The iron-bearing or Huronian series of rocks are stratified beds, the principal ore formation being overlaid by a quartzite XIV., and underlaid by a diorite, or greenstone XI. This ore formation is made up, first, of pure ore; second, of 'mixed ore' (*i. e.* banded jasper and ore); and third, a soft, greenish schistose, or slaty rock (magnesian), which occurs in lens-shaped beds which alternate with ore, thus often dividing the formation into two or more beds of ore, separated by rock. Usually the beds of both ore and rock thin out as they are followed in the direction of the strike from a centre of maximum thickness, producing irregular, lentiform masses. Since their original deposition, if we may assume they were laid down under water, the whole series, including the iron beds, have been bent, folded, and corrugated into irregular troughs, basins, and domes, which often present at the surface their upturned edges of pure ore, standing nearly vertical." (*l. c.*, p. 245.) "The trouble is to find out when a pit is exhausted, — it is so common to break through a thin layer of rock, and find a bed of workable ore behind it." (*l. c.*, p. 262.)

The proof advanced by Mr. Brooks to show the unconformability of the so-called Huronian to the so-called Laurentian, and the greater age of the latter, is in substance this: the foliation of the latter was found in two places to dip in a different direction from that of the lamination of the "Huronian" schists near by (*l. c.*, pp. 126, 156). His proof then rests entirely on the hypothesis that these planes are the original bedding planes of these rocks. This hypothesis again assumes that all are sedimentary rocks, — a point still in doubt at the time of his writing, as regarded one of the rocks at least. It is to be noticed that the two formations were not seen in contact. He also remarks (*l. c.*, p. 156): "The non-conformability is further proven by the fact that the Laurentian generally abounds in dikes of granite and diorite, which are almost entirely absent from the Huronian." Concerning certain rocks in the Menominee district we find this acknowledgment: "It must be admitted, however, that the lithological affinities of this series of rocks of the north belt are decidedly Laurentian, rather than Huronian. The gneiss and granite outcrop above described, may be almost regarded as a typical Laurentian rock in its appearance. If future investigations prove them to be Laurentian, a very troublesome structural problem would be presented here, as we would have Laurentian rocks conformably *overlying* beds, unmistakably Huronian. There seem to be fewer difficulties in supposing that the Huronian rocks of the Menominee region embrace lithological families not, so far, found represented in the equivalent series in the Marquette region." (*l. c.*, p. 175.)

Part III. of the above-mentioned work is devoted to the report of Dr. C. Rominger. We take some extracts from this: "A locality on the shore, two miles south of Marquette, where the sandstones in their contact with the Huronian Quartzites can be seen, has been previously described in Foster and Whitney's report on the Lake Superior district. We find here vertically erected white Quartzite beds of the Huronian group projecting into the lake, which have preserved their granular sandstone structure, and are distinctly ripple-marked. They are surrounded by brown sandstone and conglomerate ledges, horizontally abutting against them. The sandstones, which are of very irregular discordant stratification, closely adapt themselves to all inequalities of the cliffs, which exhibit under the sandstone covering a rounded water-worn surface, indicating their long exposure before they were enveloped by the sandstones." (*l. c.*, p. 90.)

Of Presque Isle he says: "This landspur is formed by a protrusion of peculiar rock-masses, differing considerably from the rock-beds of the Huronian group in the vicinity. Lowest is a black, unstratified, semi-crystalline magnesian rock, resembling a half-decomposed basalt or a highly ferruginous serpentine. It forms considerable cliffs at the north end of the spur; — more to the south we find it overlaid by a more light-colored, once-stratified rock, which is involved in the upheaval, with its ledges bent and broken up in great confusion." He regards this as a dolomite. It is the same rock that Houghton considered to be sedimentary, and Foster and Whitney as a volcanic ash. "On the south portion of Presque Isle this dolomite is inconformably overlaid by a conglomerate and succeeding sandstone layers, which are identical with the sandstones of the Marquette quarries. The sandstone strata some distance off from the protrusive rocks are nearly horizontal.* In immediate contact with them they have a considerable dip, corresponding to the convexity of the underlying surface. It is possible that the strata were slightly uplifted after their deposition, but I am more inclined to explain the existing dip as an adaptation of the sediments to the surface on which they were deposited. The conglomerate beds at the base are five feet thick, and contain numerous fragments of the underlying dolomitic rock and of their enclosed Jaspery minerals." (*l. c.*, pp. 90, 92.) He regards certain rocks at Light-house Point and Picnic Island as intrusive diorites, giving evidence therefor, and also remarks: "The Diorites *interstratified* with the Huronian schistose rocks in the environs of Marquette, and particularly at the Light-house point, are of an evidently *intrusive* character." (*l. c.*, p. 93.) The italics are ours, as we are anxious to know how the same rock can be interstratified and intrusive at the same point.

In a paper by Prof. J. S. Newberry, on "The Iron Resources of the United States," † we find the following statement: "On Lake Superior it is now easy to see that the ore-beds were once horizontal strata, deposited in conformity with many other stratified sediments, but they are folded and broken in such a way that their true nature was for a long while misunderstood. Like the magnetic ores of the Alleghany belt, they were once considered eruptive; but the progress of modern science has shown that all the so-called Eozoic iron ores are simply metamorphosed strata, once deposited horizontally like the sheets of iron ore now found in the unchanged Palæozoic rocks, — such as the Clinton ore and the 'black-band' and 'clay ironstone' of the Coal Measures."

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* May we be pardoned for saying that, according to Messrs. Pumpelly and Brooks (see quotations from them on the Copper district), this is proof positive that the Potsdam sandstones abut unconformably against the *Presque-islian series*, which must then have formed an island in the Potsdam sea.

† International Review, 1875, I. 754–780.

Col. Chas. Whittlesey,* in 1875, opposed the idea that the granitic region was Laurentian, but regarded the rocks as eruptive. He accepted the view of the Huronian age of the schists, however.

In the Transactions of the Wisconsin Academy of Sciences, Arts, and Letters,† Mr. E. T. Sweet calls attention to the unconformability of the Laurentian and Huronian with one another at Penokie Gap, Wisconsin. It will be seen, however, by reference to the paper, that the absolute contact was not observed.

In 1875 Mr. Brooks again took up the question of the granites in the Menomonee district, which, according to him,‡ overlie the iron-bearing rocks of that region. In order to solve the difficulty he assumes that they are the youngest Huronian rocks (Formation XX.), and immediately underlie the copper-bearing series.§

The only reason, so far as we can learn from his paper and the original observation quoted by us (*ante*, page 22), for this supposition is, that, while they are lithologically identical with the "Laurentian" rocks, he can dispose of them best by placing them as the youngest of the Huronian rocks. Furthermore, unless he did this, the "Laurentian" would be younger than the "Huronian" at this point, a conclusion that would vitiate his former statements. He therefore deliberately violates the lithological laws on which his work rests, and makes it simply a question of where each rock will fit into his system the best.

From Dr. T. Sterry Hunt's "Azoic Rocks,"|| we learn that from hand specimens sent him by Mr. Brooks he established the presence of the Montalban series, as well as the Laurentian and Huronian (*l. c.*, p.

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* Proc. Am. Assoc. Adv. Sci., 1875, XXIV. 60–72.

† Vol. III., 1875–76, pp. 40–55.

‡ Mich. Geol. Survey, I. 175.

§ Am. Jour. Sci., 1876, (3,) XI. 206–211.

|| Sec. Geol. Survey of Penn. E. Part I.

223). The greenstones of the Huronian were also said to be indigenous, i. e. rocks formed *in situ* from sediments (*l. c.*, p. 221).

We next come to the report of Mr. Charles E. Wright,* in which we are informed that all the granites of the Upper Peninsula and Wisconsin that have been examined by the writer are metamorphic. This view is based upon microscopic characters, and we should object, *in toto*, to the premise. He also states: "Some objections were made last summer (1876) by Dr. Rominger as to the non-conformability of our so-called Laurentian and Huronian series, on the ground that he had observed in several instances 'a perfect conformability of these supposed distinct series.' It seems perfectly natural to me that this should often occur; and were I to find ninety-nine places where an apparent conformability existed, and only one of decided non-conformability, the latter would, in my estimation, outweigh all the former." (*l. c.*, p. 11.) He states that a perfect case of nonconformability exists at "Penoka Gap," Wisconsin, to which we have before referred; but if we remember correctly Mr. Wright's personal statement to us, neither was the junction seen nor the kind of junction known that the two made with each other. It is too fast to assume, as has been done by Messrs. Brooks, Irving, and Wright, that the strike and dip of a foliated rock is the strike and dip of its stratification. This is especially the case when the view that they were ever stratified is still a disputed point.

Of the Huronian series the quartzite is said to show frequent ripple-marks. The soft hematite is thought to have been formed as follows: "In these mines it appears that the finely divided silica has been more or less dissolved out by alkaline thermal water, leaving the iron oxide and other bases behind." (*l. c.*, p. 15.) The iron ore is regarded as sedimentary, and Brooks's geological ideas are closely followed.

He sustains Mr. Brooks's division of the granites into Laurentian and Huronian (Formation XX.), by the statement that he finds salt cubes in the fluidal cavities of the latter, but not in the former.

Lastly, we have Mr. W. O. Crosby's paper, "On a Possible Origin of Petrosiliceous Rocks,"† in which he thinks it probable that the jasper and its associated iron ores are the representatives of a deep-sea deposit, like the "red clay" discovered by the Challenger expedition, below the depth of 2500 fathoms.

It may not be amiss to incidentally refer to the treatise of Mr.

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* First Annual Report of the Commissioner of Mineral Statistics for the State of Michigan, 1879.

† Proc. Bost. Soc. Nat. Hist., 1879, XX. 160-169.

D. C. Davies on Metalliferous Minerals and Mining.* It would be difficult to imagine a description or a section so at variance with the facts as the ones that he gives on pages 274 and 275. We feel that all geologists who have been in this region will be surprised to be informed that "lingulæ are abundant in the overlying sandstone." On page 149 he has represented the copper-bearing rocks and sandstone (Potsdam) as resting directly upon, and at a steep angle dipping away in both directions from, the iron-bearing rocks; also, the western copper rocks as dipping east, and resting upon a similar set of iron rocks. It is to be hoped that the rest of his book is not so erroneous as this.

Historical Summary.

In general, then, in looking over the views advocated by past observers, we find, in brief, the following opinions held.

The rocks† of this district were all taken as azoic by Foster and Whitney, and not considered to be capable of subdivision into geological periods. We must also notice that Prof. H. D. Rogers regarded them as of primal or Potsdam age. On the other hand, we find that this formation is divided by Murray, Hunt, Kimball, Winchell, Credner, Brooks, and Wright into the Huronian and Laurentian. This division is based upon lithological characters, and an unconformability said to exist between the two. Rivot considered the whole as Potsdam.

The granite is regarded as an eruptive rock by Foster and Whitney, Bigsby, and Whittlesey; and as of sedimentary origin by Rivot, Kimball, Brooks, Hunt, and Wright. These latter, with Credner, take it as being older than the schistose rocks associated with the iron ores, and, excepting Rivot, with its accompanying gneissoid rocks composing the Laurentian formation. Foster and Whitney and S. W. Hill regarded the granite as younger than, and eruptive in, the schists.

The gneisses and schists were taken by all the observers as being of sedimentary origin, except possibly Whittlesey, whose language is as obscure as the formations about which he writes.

The metamorphism of the schists is supposed by Hubbard, Rivot, Kimball, Hunt, Brooks, and Wright to be occasioned by chemical agencies accompanied, as part thought, by galvanism. Foster and Whitney and Bigsby considered that the metamorphism was brought about by the presence of eruptive rocks, and their accompanying chemical agencies. Foster and Whitney regarded the "diorites" of this region as eruptive rocks, but Rivot, Kimball, Hunt, Winchell, Credner, Brooks, and Wright, as sedimentary ones and interstratified with the schists.

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* London: Crosby, Lockwood, & Co., 1880.

† Excepting the sandstone, which will be spoken of in our remarks on the Copper district.

The iron ores are regarded as all of sedimentary origin by Foster, Kimball, Dana, Hunt, Winchell, Credner, Brooks, Newberry, and Wright, but are believed for the most part to be of eruptive origin by Whitney, and by Foster and Whitney. These ores were said to be in the upper portion of the Huronian series by Kimball, Brooks, and Wright, with the "diorites" underlying them.

It will thus be seen that, while Foster and Whitney regarded certain of the rocks in the "Huronian" as eruptive, Hubbard, Rivot, Kimball, Hunt, Credner, Brooks, and Wright regarded all, with a few slight exceptions, as sedimentary; and Houghton, Hubbard, Locke, Kimball, Rivot, and Brooks teach that they pass by gradual transition into one another.

The most important points, then, about which there has been or is difference of opinion, are the age and relation of the granite and schists, the origin of the diorites and iron ores, the passage of one rock into another, and the presence or absence of eruptive rocks. These and other questions relating to this district admit in many cases of no middle ground; one or the other party must be mistaken in their observations or conclusions, or both. All these questions lie closely to the fundamental propositions of geology; they reach to the superstructure of the science.

Methods of Observation.

The object of the writer in visiting the Iron district was to clear up some of the preceding mooted points in the geology of that region, if possible, especially the origin of the iron ores and their relations to the country rock.

From our personal experience in both regions, we should hold that the ordinary methods of geological research which are employed in the study of the comparatively undisturbed and unaltered sedimentary rocks of the Mississippi Valley are not sufficiently accurate for our purpose in the Lake Superior district, where the rocks are foliated, disturbed, and of mixed eruptive and sedimentary origin. Stratigraphical laws that hold good in the former region do not in the latter, especially when it is sought to connect together two rocks of unlike character, or when the nature and origin of either or both is a point of dispute. In this disturbed district the presence of a rock in one place will hardly prove the presence of the same one in another, except by direct connection, even if the two do look alike, especially if that sameness is questioned. If the two rocks are identical in structure and composition, nothing but the proof of direct, absolute continuity places the question of their identity beyond dispute here, especially if we have any reason to suspect the eruptive origin of one or both of them. Lamination, banding, joint planes, cleavage, pseudo-stratification, and fluidal structure, are not to be taken as proof of stratification in doubtful rocks. The very origin and nature of all, except, perhaps, the true fluidal (not pseudo-fluidal) structure, are yet open questions. Until it is proved that they are confined to one class of rocks, it is unsafe to use them to prove that any questionable rock belongs to that class. Doubly so is it when it is well known that they are not so confined. If they are not to be used to determine the sedimentary origin of a rock, in like manner the dip and strike of such structures ought not to be taken to prove order of superposition, conformability, or non-conformability, especially as this proceeds upon the supposition that both rocks in question are sedimentary. That a sedimentary rock is horizontal, or has a certain dip at one place, is not to be taken as proof of what its position must be in another locality, unless the conditions remain the same.

It may be said that every rock carries in itself, or in its relations to its associates, or both, its history, more or less complete. In order to read and understand this history, it seems necessary that we should be able to distinguish between the fragmental and non-fragmental forms; the characters assumed by a lava flow and its associated detritus, their relations to one another and to the over and underlying rocks; the characters of an intrusive rock, its effect upon the country rock, and the nature and kind of junction that they make with each other; the relations that sedimentary rocks have to their over- and under-lying rocks; and the alterations to which all classes are subjected. One of the most common errors made, is by observers taking the ground that two outcropping rocks that look alike are of necessity the same geologically, and form a continuous whole, although no direct connection is proved.

It now remains for us to enter upon the questions before us.

The Jasper and Iron Ore.

The country rock is of a varying nature, but is mainly composed of schists (largely chloritic), argillites, and quartzite, in that part of the district visited by us. Associated with these rocks is the jasper, which is acknowledged on every hand to be an inseparable part of the iron ore formation. The origin of one gives the origin of the other. Their interdependence is such, and has been so regarded, that the relations of one to the country rock give the relations of the other. The two have been so fully described in the past, that it is only necessary to briefly describe them here.

The common form is that of interlaminations of jasper and iron ore, the laminæ varying from extreme tenuity to considerable thickness. In some places the jasper predominates, in others the ore. In the last case we have a more or less valuable ore, according to the amount of the siliceous material, which, however, may exist only in a mere trace. The purer parts form large masses, that are mined, and which graduate into the jasper, or ore containing so much jasper as to be unfit for working. The workable parts are frequently lenticular in form, although often irregular. The irregularity of the ore mass, its passage into the jaspery ores, and the uncertainty where the next mass will be found, are among the chief difficulties of the miner. The origin of the jasper and ore becomes then a problem of great economic importance, as do also the relations of both to the country rocks. The permanence and extent of the formation, whether it is in the form of vein deposits, eruptive (intrusive or overflow) masses, or sedimentary deposits, are questions in which the capitalist and miner, whether they will or not, are most deeply interested. As they have never been regarded as vein deposits, there remains for us only the question whether the jasper and its associated ores are eruptive or sedimentary in origin.

Lest there be some misunderstanding as to to the reason for thus dismissing the theory of the ores here being vein deposits, we would remark that the question has been ably and fully discussed before in the works of previous observers. Furthermore, while veins on a small scale are occasionally seen, we were unable to find upon either the jasper or its associated ore a single character belonging either to a vein or an infiltration deposit. It therefore seems unnecessary to discuss the vein or infiltration theory here.

As both the eruptive and sedimentary origin of the jasper and the ore have been advocated by some of the most eminent geologists in this country, it is necessary that the question should be answered by the facts, and not by any preconceived theory or idea. The question now is what are the facts, and their most probable explanation. The first and most important thing to be observed in deciding this is the relation of the jaspery formation to its country rocks.

This relation is well shown in and about the Lake Superior mine at Ishpeming. On the north side of one of the abandoned pits just east of the main workings, the junction of the jasper and ore with the chlorite schist was observed and figured. (Fig. 1.) Specimens were also taken that show the contact (143, 144, 145, 146, and 147).* The junction of the two is very irregular, the banding of the jasper and ore following the irregularities of this line, while the schist is indurated and its laminæ bear no relation to the line of contact. Stringers of ore project into the schist, which near the jasper is filled with octahedrons of magnetite. The schist loses its green color generally, and becomes apparently an indurated argillite. The contact and relations of the two rocks are not such as are seen when one sedimentary rock is laid down upon another, but rather that observed when one rock is intrusive through another; and in this case the intrusive one is the jasper and its associated ore. On the south side of the same pit the jasper bows in and out in the schist, forming at one place a projecting knob whose banding follows its contour. Lying against it is a long arm of jasper, similarly banded, which ends in a rounded knob. This is represented in plan (Fig. 2), and specimen No. 150 was taken from the end of the latter projection. In the southwest corner of the same pit a dike of very fair hematite ore (155) about one foot in width breaks at an angle of 15° across the argillite (154) and schist, whose lamination is vertical. (Fig. 3.) Wherever the unbroken contact of the jasper and ore with the schist could be observed, that junction is seen to be an eruptive one, on the part of the former (156, 157, and 158). At the School-house mine east of the Lake Superior mine, the jasper forms a dike with a knob-like ending, the lamination (banding) following the curvature of the sides. The contacts between the ore and schist were well-marked eruptive ones (168, 169). Overlying the ore was found on one side a ferruginous and quartzose breccia and conglomerate composed principally of the ruins of the underlying ore and jasper (166, 167). A similar but finer-grained rock, mostly a quartzite, forms the hanging, or better the fallen wall of the New York mine. This is composed, in like manner, chiefly of the *débris* of the underlying ore and jasper. Mr. Brooks's statement regarding the "quartzite" of the Marquette district (p. 18) is undoubtedly true of this rock, that when he finds the "quartzite," adjacent to it will be found all that is left of the ore formation. This, however, is not what Mr. Brooks intended in his statement, as these detrital rocks apparently form but a small portion of his "quartzites." These of course mark old beaches water-worn after the jasper and ore were *in situ*, in nearly their present condition, and, if the logic of the geologists of the Michigan and Wisconsin surveys were carried out, these unconformable detrital formations would mark a new geological age.

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* The numbers enclosed in marks of parenthesis refer to specimens collected by the writer, and deposited in the Lithological Collection at the Museum of Comparative Zoölogy.

One difficulty found in mining the iron ore has arisen from the schist being found in large masses, broad at the upper part of the mine, but tapering out to thin wedge-shaped masses below, which are left without support when the ore is removed. This renders one wall, and sometimes both, unsafe, no one foreseeing when the support to the treacherous schist will be removed. This structure evidently is consonant with the theory of the eruptive origin of the jasper and ore. They break obliquely up through the schist, and send off branches, which, pursuing the same general course, leave wedge-shaped masses between them and the trunk. The ore when removed allows that which has been supported by it to fall. This very cutting across the lamination, however slightly, would tend to let all severed masses slide out, even if they were cut on one side only. Figure 4, taken from an actual section in an old working at the southeastern end of the Cleveland mine, Ishpeming, shows the phenomenon very well, and its cause. The branches of ore are about two to three inches wide here, the main body being about twelve inches in thickness, and the relations can be well studied. In several places near this point the irregular wavy line of contact between the schist and ore can be seen; and all bodies of this or the jasper were found on close examination not to coincide with the lamination, however much they may appear to do so.

At the upper portion of the Jackson mine, Negaunee, the jasper and hematite were seen to cut across and obliquely up through the schists. A vertical section as shown by the former mining done at this point is given in Figure 5. The jasper also curves in a similar manner at right angles to this nearly east and west section. While this (the figure, not the actual occurrence) could be explained easily by sedimentation, it is fatal to the view of conformable deposition. In pit No. 3 of this mine (Jackson) the ore breaks irregularly through the schist, forming a brecciated-looking mass, while in other cases it runs up into the schist ending in irregular knobs. Figures 6 and 7 show some of the occurrences observed and figured from the pit walls. Figure 8 represents a section about forty feet in height at the west end of No. 7 pit in the same mine. The schist shows bending and dislocation as represented in the curve *b*, *c*, which shows the direction and manner of the upthrust. The point *a* is at such an elevation that we are not able to assert that it is part of the same formation. It certainly looked the same, and the assistant captain in charge of the pit stated that he knew they were the same. The entire mass of jasper and ore represented here had been so acted upon by secondary agencies that it had been mined as "soft hematite." In the same pit a beautiful brecciated jasper occurs in which the hematite forms the cementing material (269, 270, 271, 272).

In pit No. 4 a wedge of ore and jasper was seen intruding between and across the lamination of the schist. (Fig. 9.) In the "north pit" the eruptive character of the ore is well shown; Figures 10, 11, and 12 showing sections exposed on the walls. Overlying the ore at a low angle is a quartzite containing jasper and ore derived from its underlying ore (277). At the Home mine in the Cascade range the ore was largely a sandstone impregnated with hematite (257), strike N. 70° W. with a northerly dip, which varies owing to the contortion of the strata from 30° to 70°. Several dikes of jasper run through this sandstone, in part conforming to the bending of the strata, and in part breaking across the laminæ (258, 259, 260, 261). Specimen 259 shows well the contact between the two rocks, the jasper and sandstone, which contact in a less degree is shown by the other specimens. One of these dikes is represented by Figure 13, in which the width is exaggerated compared with the length. There is no mistaking the intrusive character of the jasper and its interlaminated ore here. It is of course almost unnecessary to state that this mine, having as its chief ore a ferruginous sandstone, was long since abandoned. The quartzite (metamorphosed sandstone) which forms the hanging wall of the Pittsburg and Lake Superior mine, Cascade range, has been cut through by dikes and little stringers of nearly pure hematite (262, 263, 264), which in its present position is distinctly intrusive. While in general these little dikes follow approximately the bedding, they are seen not to exactly do this, but cut the laminæ obliquely through much of their course. This mine contains as a secondary formation much specular iron (265). Near the bridge over the Palmer mine the jasper shows well its eruptive character in its junction with the quartzite, while the banding is seen to be parallel to the contact line. This jasper holds in it, and as part of itself, the hematite mined here.

It is advocated by Messrs. Credner and Brooks that all the iron was originally in the state of magnetic oxide, this view being sustained by the crystals of martite found in various parts of the district.

It would seem that a microscopic examination of the banded jasper and ore should give us some facts bearing upon the question. A section was made of a finely-banded jasper (136), taken near the Lake Superior mine. Under a lens this shows a fine contorted banding. Microscopically this section is composed of a fine granular aggregate of quartz and hematite, and a more coarsely crystallized portion made up of octahedrons of magnetite or martite, and of quartz of secondary origin. The quartz in the first part is largely filled with minute globules and grains of ore, which also occurs in irregular masses and in octahedrons. The quartz associated with the more coarsely crystallized portion is water clear, and shows the usual fibrous granular polarization of secondary quartz. Wherever the iron is in a distinguishable crystalline form it is in octahedrons. The color and streak of the iron in the hand specimen are those of hematite, but the powder is found to be magnetic. No. 153, from the same locality, has similar characters. The section was taken from the most jaspery portion, and shows much of the fine aggregation of quartz and hematite. The structure of the quartzose portion is like the devitrification structure of the rhyolites and felsites. The section has been repeatedly fissured, and the fissures filled in with secondary deposits of quartz and octahedral crystals of iron. So far as we have observed, the brecciated jasper and ore have had their fractures filled in like manner. No. 271, from pit No. 7, Jackson mine, is of similar character. The jaspery portion is finely banded, and shows an apparent fluidal structure. We are inclined to regard the structure as fluidal, but in a rock so deeply colored it is difficult to make satisfactory examinations. This is the only section that shows anything like a well-defined limit between the jasper and ore bands, under the microscope, as pointed out by Dr. Wichmann.* The powder of the two last-described specimens is feebly magnetic. No. 262 was from the Pittsburg and Lake Superior mine, Cascade range. This shows the intrusion of the iron ore through the quartzite (p. 32). The ore gives the hematite streak, is feebly magnetic, and appears to be in octahedrons. The quartz is much fissured, showing the effect of heat, and contains microlites and fluid and stone inclusions.

The octahedral form of the iron ore would sustain the view that it was all originally magnetite. The difficulty lies in proving the crystals to be primary, and not secondary forms, especially as they are largely associated with secondary quartz, and also are abundant in the little fissures (minute veins) traversing the jasper. Our microscopic examination of rocks of various ages and characters goes to show that all rocks, especially the older, have been subject to more or less alteration. This alteration is accompanied by recrystallization, which often obliterates the original characters. This change appears to be produced through the medium of the percolating waters, and consists rather in a chemical rearrangement of the constituents of the rock amongst themselves, than in the deposition of any material brought in from extraneous sources. The jasper and iron ores, as well as all other rocks examined microscopically from this district, have suffered this alteration to a greater or less extent; therefore it is perhaps impossible at present to be sure of the original state of the iron, or how many changes have taken place.

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* Geol. of Wisc., III. 615.

Without objecting in any degree to the idea that the ore was originally magnetic, certain facts indicate that the present magnetic state of the iron is in some places due to secondary causes; i. e. the heat of intrusive rocks erupted since the iron ore and jasper were in place. While in general the Republic Mountain ore is hematite, exceptions exist. On the northerly side of the hill a "diorite" dike was seen (91, 92). It is found that the ore was so affected by the heat of this intrusive mass that it is magnetic adjacent to it (90), while a short distance away it is the normal hematite. Numerous other localities were examined about the hill where these secondary intrusions occurred, with the same result; the iron ore was magnetic adjacent to the dikes, but not magnetic a short distance away. As a general rule, the magnetite or the hematite pseudomorphs after it (martite) are found near the "quartzite" of Brooks in this mine. Those who examine the map of Republic Mountain, prepared by him,* will observe on the northern side of his "quartzite," a queer tongue of it projecting into the hematite. An examination of this tongue at different places shows the following facts. It contains numerous rounded and irregular fragments of the iron ore in it; these fragments occur on both edges (93, 94, 96), while the centre of the mass is free from them (95). At this point it varies from a few inches to two feet in width, and it is seen to break across the lamination, although nearly coinciding with it. At another part, shown near the same pit, No. 8, this rock and its contact with the "jasper" and ore were well marked. The "quartzite" (115, 118) is firmly welded to the ore, and breaks across the laminæ, cutting them, and sending tongues into the mixed jasper and ore (116, 117, 119). The junction is an eruptive (intrusive) one, and not that belonging to the contact of one sedimentary rock with another. The ore at the junction is magnetic. The question whether this is an intrusive or sedimentary rock has another side than the simple scientific one. It makes a great difference in the mine whether this is a simple overlying metamorphosed sandstone, as Mr. Brooks places it, or a later intrusion cutting the ore below. This latter case opens up numerous questions that the practical man can only disregard to his cost, sooner or later, but which have nothing to do with the present discussion.

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* Atlas, Geol. of Mich., 1869 – 73, Plate VI.

As this rock seems to belong to the granites, it will be described under them (p. 54). Should future research show that all of the "quartzite" of Republic is the same as the tongue is, it would have a bearing on the proximity of the magnetite and martite to it.

In like manner, passing to other mines where secondary intrusions are more abundant, the magnetite becomes a more prominent feature. It seems, so far as we have seen, that the magnetite and martite are directly proportioned to the amount and proximity of eruptive rocks, extravasated since the ore was *in situ.*

East of the Old Washington mine, Humboldt, the actinolite schist (310) and jasper with its ore (magnetite) were seen within one hundred feet of one another, but dipping in opposite directions; three hundred feet farther west they both dip in the same direction, while a few rods away the magnetite (311) with the jasper is seen breaking irregularly through the schist (312), and sending tongues into it.

The intrusive nature of the ore was well marked here, but it was very difficult to procure any hand specimens showing it (313, 314, 315, 316). An attempt had been made to mine the ore at this locality. Three rods to the east the ore and jasper were seen intruding in long tongues and sheets between the planes of the schist, as well as breaking across the lamination (317, 318). The same structure is very well marked in the rocks that form the bluffs between the Old Washington and Edwards mines. The ore with quartz (325) sends long tongues up between the laminæ of the actinolite schist (326). Although in part these coincide with the bedding, yet in many places they break obliquely across it, showing their intrusive character in an unmistakable manner.

It would seem that this intrusion between the planes (intrusive sheets) in this locality probably took place when the schist was in a somewhat unconsolidated condition, the intruded rock serving as an efficient agent of metamorphism. The effect produced by the ore and its relations to the schist are not such as we should expect, or are accustomed to see, when a rock is intruded through one indurated as the schist is now. The ore at the New Washington mine is magnetite, and it was seen in distinct well-marked dikes, as unmistakable as any dike, breaking obliquely up through and across the argillaceous schist, No. 340 showing the contact of the two. These dikes were sometimes narrow, being only about one foot wide, with well-marked junctions with the schist on both sides. The ore is more strongly magnetic and affected in its character adjacent to the dikes that later cut through it than in other portions of its mass (p. 43). The dikes of magnetite, with the other dikes, have greatly affected the schist through which they pass, forming an ottrelite schist (p. 45). At the Champion mine the ore is both magnetite (356) and hematite (355), and both are frequently found in a single hand specimen (357, 358, 359). At the Keystone mine, east of the Champion, a dike of magnetite about six inches in width was observed.

The Basic intrusive Rocks, Schists, and Felsite.

At Marquette, south of, but near, the lighthouse, a dike (3) of about seventeen feet in width cuts across the schist (1, 2, 5,), the latter dipping north seventy degrees. The contact of the dike with the schist is a well-marked intrusive one, the schist being indurated at the point of contact (4). (Fig. 16.) Microscopically, the rock of this dike (3) is composed of plagioclase, some orthoclase, quartz, hornblende, biotite, viridite, magnetite, hematite, and some probable pseudomorphs after olivine. The feldspar contains numerous microlites and inclusions, and it appears to be the only original constituent of the rock left in a determinable condition, except the magnetite. The schist (2) is composed of a fine-grained groundmass of aggregately polarizing quartz, holding greenish ragged hornblende crystals and grains of magnetite.

Many dikes occur in this vicinity, and their intrusive character has been noticed by Credner, Rominger, and Julien. Some dikes (8) were seen running north and south, cutting the east and west ones. The relation of one of the latter to the adjacent schists is shown in Figure 14. In the quarries near the light-house numerous dikes were seen. Their lines of junction with the schists (47) could readily be made out, and hand specimens obtained showing it (45, 46, and 48). (Fig. 15.) Four of these dikes were counted within a distance of two hundred and thirty-two feet, one of which was sixty-six feet in width (49). The locality is the place from which the stone for the Marquette breakwater was obtained. These dikes, like the majority running east and west, nearly, but not quite, coincide with the bedding (45, 46, 47, 48, 49). A specimen of one of these (45), taken near the edge of the dike, is composed of plagioclase, orthoclase, magnetite, titaniferous iron, hornblende, viridite, quartz, epidote, and augite. The augite is generally nearly altered to hornblende and viridite, only a little of the distinguishable augite remaining in the centre of the crystals. The other constituents, except part of the feldspar and the iron, bear the characters of alteration products. A section adjacent to the junction with the schist shows much higher alteration. The augite has disappeared, the iron has been nearly all altered to "leucoxene," and secondary orthoclase is abundant. The schist from the same specimen (45) is composed of quartz, argillaceous material, chlorite, hornblende, magnetite, "leucoxene," and a little augite. It would seem that this has been formed from detrital material of the same nature as the dikes (basaltic). The close resemblance of the "diorite" and schist in mineralogical characters, but not in structure, is shown in another section containing the junction of the two rocks (48). No. 49, taken from the centre of the dike, sixty-six feet wide, running parallel with and belonging to the same system as the others, is composed of plagioclase, augite, magnetite, olivine, and some viridite. Long microlites of apatite traverse the mass in various places. The feldspar contains numerous inclusions of the original base, more or less altered, of the same general structure, relations, and arrangement as is commonly seen in the feldspars of modern basalts. The portions of the base originally left in the crystallization of the molten magma in the interstices between the crystals has been changed to a grayish or brownish fibrous substance, also to viridite. The augite is comparatively fresh, and cut by the feldspar crystals. The structure of the rock is that belonging to the more coarsely crystalline basalts. The altered base is probably the "inserted substance" of Drs. Zirkel and Wichmann.* It would seem that some of the above rocks are like the "diorite" of Dr. Wichmann from this locality (*l. c.*, p. 629). We feel that the lithologist who was unacquainted with the field relations of the preceding specimens would declare it impossible that they could be from the same series, apparently identical in age, and originally so in composition. South of Marquette the schists (11) are more argillaceous, forming true argillites, although chloritic in places. Numerous dikes were seen here, but the rock is more altered, and perhaps was extravasated earlier than most of the dikes on Light-house point (9, 10, 12). No. 12 is composed of feldspar, quartz, viridite, opacite, and pseudomorphous remains of hornblende fragments. But little of the feldspar shows the twinning of plagioclase. The structure of the rock renders it probable that it was originally an andesite. On Light-house point, lying just north of the dike (No. 3, page 36) first described, and older than it, is an intrusive felsite (quartz porphyry). It is to be here noted that Mr. T. B. Brooks states: "It may be confidently asserted that no porphyry occurs in the Marquette . . . . Huronian";* also that this locality has been studied by Messrs. Julien, Credner, Rominger, and others, without finding this felsite.

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* Geol. of Wisc., III. 624.

This felsite is eruptive generally along the lamination planes of the schist, but at certain points breaks through and across those planes. Figure 16 gives a good idea of its relations to the schist and diabase, for such we regard the rock of the dike to be. A short distance to the north, on the opposite side of this immediate spit of land, its eruptive character is better marked than in the first locality.

The felsite (6) on its weathered surface is colored pinkish and greenish white, showing fluidal structure, and holding crystals of quartz and pinkish feldspar. On the fresh fracture the groundmass is felsitic, of a greenish-gray color, and holds the same crystals. Pyrite is seen in the fissures. The groundmass is now altered to an aggregate polarizing mass, principally of quartz and mica. The fluidal structure is seen in the thin section, and greenish and brownish mica is largely segregated along the fluidal lines. The feldspar is entirely decomposed, having about the same composition and structure as the groundmass, but holding more argillaceous material and less quartz. Chlorite and magnetite were observed. The original quartz grains are filled with fluid and vapor cavities, and also contain some stone cavities and microlites. Northwest of the light-house a more quartzose felsite (7) was found on the side of a bluff overhanging a little ravine. This felsite is very much jointed, breaking into small rhomboidal blocks, and cuts through the schists nearly, but not quite, coincident with their lamination. It is a grayish-white rock containing crystals of feldspar, quartz, and pyrite. Microscopically, the groundmass is now altered to a fine granular aggregate, as in the preceding, holding quartz, muscovite, greenish mica, and pyrite. The feldspar is altered the same as the groundmass, and contains similar minerals. The original quartz grains contain microlites, stone inclusions, fluid cavities, etc. We regard these felsites, from their structure, not as the equivalents or precursors of the Tertiary rhyolites, but as identical with them, the present difference between them being due to secondary alteration, and perhaps their somewhat greater depth at the time of consolidation than the part of modern dikes reached by us had.

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* Geol. of Wisc., III. 660.

On Picnic Point, north of Marquette, a coarsely crystalline diorite (50, 51, and 52) occurs, forming the main portion of the point. This rock contains pebbles and fragments (53, 54) in some places. Some of the fragments of schist are large, and one long band of it was seen. This schist is much indurated, especially near its contact with the diorite (58, 59), and forms an irregular junction with it (57). Picnic Islands, just off the point, are composed, in the main, of the same rock (60).

On the North Island, a diabase dike (61), about twenty-eight feet wide, cuts the "diorite," running S. 80° E. Another dike was seen running the same way, on the Middle Island. The "diorite" is somewhat brecciated. On Picnic Point a hornblendic granite (55) cuts up through the diabase, and includes numerous fragments of it (56). The general structure and relations of the granite to the "diorite," as well as the rounding off of the "diorite" fragments, are shown in Figure 17. The order is, then, 1st, the schists; 2d, the "diorite"; 3d, the granite and diabase, — the question of the priority of either not having been settled.

The "diorite" (50) is a grayish-black rock composed of hornblende crystals, with reddish feldspar, epidote, and pyrite. Microscopically, it contains the same minerals with magnetite and apatite, as well as chlorite, quartz, viridite, and other alteration products. The feldspars are greatly altered, give aggregate polarization, and are filled with alteration products.

The most coarsely crystalline specimen (52) is a grayish-green rock, composed mostly of short, thick hornblende crystals, showing well-marked cleavage. With the hornblende a small amount of feldspar occurs. Under the microscope, besides these, augite, chlorite, quartz, titanite, hematite, actinolite, and magnetite were seen. The hornblende and chlorite appear to be products of alteration from the augite, and the hematite from the magnetite. Some of the feldspar can be recognized as plagioclase, and it would seem that the rock was originally composed of feldspar, augite, and magnetite, while the other constituents are alteration products. The quartz contains fluid and vapor cavities.

The diabase dike rock (61) is a dark gray crystalline one, holding ledge-formed feldspars and weathering brown. In the thin section it is seen to be composed of plagioclase, a little orthoclase, augite, olivine, magnetite, hematite, viridite, and apatite. The feldspar encloses bits of the original base, part of which is now devitrified, but part remains as an unchanged globulitic base. This affords additional proof that the diabases are simply old crystalline basalts. The augite is quite clear and unaltered except in some places. The olivine is considerably changed, yet the centre frequently shows the unchanged mineral. These olivines, like those in modern basalts, are in fragments, grains, and rounded and penetrated crystals, showing in this way their prior origin to the crystallization of the rock *in situ.*

In the sketch of the literature given before, it is seen that Messrs. Rivot, Kimball, Hunt, Winchell, Credner, Brooks, and Wright regard the so-called "diorites" as sedimentary rocks, metamorphosed *in situ*, and in general teach that they gradually pass into the schists on either side; i. e. they form one and the same inseparable series of sedimentary deposits. This passage, by insensible gradations, it is said, was established by the field observations of all except Dr. T. Sterry Hunt, who, it seems, based his conclusions upon lithological evidence; for we fail to find the slightest evidence in his writings that he had any personal acquaintance with the district. On the other hand, Messrs. Foster and Whitney taught that these rocks were intrusive, basing their conclusions upon their observations in the field.

Special pains were taken by us in the field to see which of the two views were correct. Where the conditions were such in the field that any evidence could be obtained bearing on either side, that evidence was always of the positive kind, and sustained Messrs. Foster and Whitney. The evidence of the six observers quoted on the opposite side was of the negative kind; i. e. they could not or did not see any distinct junction between the two rocks; therefore it was assumed that none existed. Where the contacts were covered, or broken and obliterated by frost and atmospheric agencies, the proof on either side is *nil;* but when such is not the case, and we have on one side "diorite" and on the other schist, the question is, Do they or do they not pass into each other? Both rocks are of a greenish hue generally, and to the eye untrained to observe the minutest changes and differences in rocks, they look alike. It is therefore to be expected that the majority, at least, of observers will walk directly over the junction between two rocks, especially if they believe in the prevailing theories, and declare that they pass directly into each other by insensible gradations. The only thing such negative evidence gives in this case is the proof that either the observer was unskilled, or else his work was not done with sufficient care, perhaps both. The line of contact is, when found, a distinct separation between the two rocks; on one side of which is to be seen schist, on the other "diorite." They no more pass into each other than do oil and water in the same vessel, although it might not be impossible that some would not be able to say where one ended and the other began. The contact of the two rocks is so well marked that hand specimens (171, 172) can be obtained showing it; therefore our proof that they do not pass into each other, but are entirely distinct formations, can be examined not only in the field, but also in the cabinet, and if need be under the microscope.

Such a contact between the schist and "diorite" can be seen a short distance east of Ishpeming, where the carriage-road, near the railroad leading to Negaunee, bends around a low "diorite" knob. This junction is represented in plan (Fig. 18) by a sketch made on the spot, and shown by specimens 171, 172. The "diorite" at this point appears to have passed obliquely up through and over the schist. The relation that the two have, the kind and manner of contact, are those belonging to an eruptive rock breaking through and partially over another. It is almost needless to say that the "diorite" is the eruptive rock here. Many of the "diorite" hills, if not all, are composed of dikes of the "diorite," with schist and argillite lying between. The lamination of these interlying masses is of course generally perpendicular to the pressure, i. e. parallel with the dikes. This can be well seen in the hills south of Teal Lake, Negaunee, as well as just northeast of the Cleveland mine, Ishpeming. At the latter place the "diorite" is seen to break obliquely through the schist, and the line of junction can be easily seen. (Fig. 19.) So far as can be told, the "diorite" comes out obliquely over the schists connected with a narrower neck below, as shown in ideal section. (Fig. 20.) This would indicate, we think, that this is somewhat near the old surface of eruption. This hill was seen to be made up of several "diorite" dikes, with schist held between them. The contact of two of them with the schist is shown in Figures 21, 22.

At Negaunee, on a little elevation between Main Street and the Marquette, Houghton, and Ontonagon Railroad, the "diorite" is seen to break through the schist, and to send small veins into it. On the "diorite" ridge south of Teal Lake, the "diorite" is seen (243+, 282, 283) to have cut through and enclosed between it some schists and argillites. This rock is very columnar, and has the general character of an eruptive mass. Its junction with the schists is well marked, and was observed in various places. One specimen is seen to be composed of augite, hornblende, feldspar, viridite, titaniferous iron, and epidote (243+). The augite is much altered, changed to viridite and hornblende. Another section (283) shows no augite, this mineral being entirely replaced by the secondary hornblende. The feldspar is so greatly changed that only part of it shows its triclinic character. Of a similar character to No. 283 are Nos. 238+ and 239+, from the "diorite" south of Lake Superior mine, neither showing any augite, although the hornblende is doubtless secondary, as in the others. No. 239+ is more coarsely crystalline and granitoid in its structure.

The "diorite" (180) lying between the Lake Angeline and Salisbury mines is seen in the thin section to be composed of plagioclase, hornblende, biotite, epidote, viridite, and titaniferous iron with its alteration product. Of these only the feldspar and titaniferous iron are apparently original constituents.

The diabase (175) forming the southeast side of the Salisbury mine is a dark gray crystalline rock, holding ledge and tabular formed crystals of feldspar, and weathering to a rusty brown. It makes a most beautiful section under the microscope when studied in polarized light. It is composed of plagioclase, orthoclase, augite, magnetite, olivine, viridite, and hematite. The plagioclase cuts through the augite, leaving it in cuneiform and irregular masses. The olivine is in rounded and irregular grains of prior origin to the crystallization of the rock, and is held both in the feldspar and in the augite. It holds a similar relation here to the feldspar that it does to the enstatite in the Presque Isle peridotite. While the central portions of the olivine are sometimes clear and unchanged, the grains are generally altered to a greenish or brownish serpentine. A little fissure traverses the section, cutting and connecting a number of the olivines. This fissure can be readily traced under the microscope on account of its having been filled throughout its extent with the greenish serpentinous material derived from the olivine. The feldspar is in some cases nearly filled with stone inclusions, arranged parallel to the crystalline faces. These inclusions are evidently inclusions of a devitrified base. This dike is said to ascend by steps, not in a straight line.

Near Deer Lake, northwest of Ishpeming, a "diorite" dike running N. 45° W. (231) was seen cutting a breccia and conglomerate (229, 230). This "diorite" is so altered that it resembles a chlorite schist, and in the thin section is seen to be composed of chlorite, quartz, and mica. It holds some ferruginous masses resembling the product of the decomposition of titaniferous iron, as well as one or two that probably resulted from the decomposition of olivine or brown hornblende. The quartz contains fluid inclusions. The groundmass is now composed entirely of scales, plates, grains, and microlites belonging apparently to chlorite, mica, and quartz, and with the exception of the ferruginous decomposition product no trace of the original structure and constituents remain. We regard the rock simply as a more highly metamorphosed condition of the "diorites" of the region; but were it not for its field relations we should not be able to tell its history from microscopic examination. In such a case as this, with our present knowledge, the microscope fails to give us any idea of its origin, whether eruptive or sedimentary. Probably every lithologist, in examining this section, would pronounce the rock to be sedimentary, yet we know it to be eruptive, and probably in its original state a basalt. This well illustrates the danger of deciding upon the origin of such highly altered rocks by microscopic analysis alone, and calls attention to the necessity of carefully ascertaining their relations in the field.

One mile northwest of Deer Lake, west of the road, a high hill was seen composed principally of "diorite" (232) running about north and south. The contact of this "diorite" with the country rock is well marked on both sides. On the west side it cuts a conglomerate, and on the east a finer-grained fragmental rock (233). The contact is an irregular eruptive one, and the country rock is indurated near it. At the south pit of the Jackson mine, from which "soft hematite" is taken, a diabase dike forty feet wide was observed running N. 30° W., and cutting the ore. It was said that in mining its course had been found to be variable. This diabase is a grayish brown, coarsely crystalline rock composed of plagioclase, orthoclase, augite, brownish decomposed olivine, magnetite, and ferrite (278). The plagioclase is but very little decomposed, and is beautifully striated. The diabase (280) near its walls was very much decomposed, and its olivine, augite, and magnetite form a dark brown decomposed mass cut through by the feldspar crystals, which are kaolinized, forming feebly polarizing masses. Were it not known that it is part of the diabase, it could only be recognized as such from the position and arrangement of its kaolin pseudomorphs relative to the remaining portion of the section.

In the Washington mine several dikes of "diorite" and melaphyr cut the ore, which is strongly magnetic in contact (327, 328) with them. The melaphyr (329, 342) encloses a horse of jasper and cuts the "diorite." It (329) is composed of plagioclase, a little orthoclase, augite, magnetite, and viridite. The structure is that belonging to basalts, and the rock is comparatively little altered considering its age. The feldspars contain inclusions that appear to have been portions of the original base, but which, as well as the base adjacent, has been altered to a grayish-white globulitic and fibrous material. This shows largely the structure of the original globulitic base, but wants the black color. The fibrous alteration product of the base has been confounded with the true original micro-felsitic base of the andesites by lithologists generally; as is the inevitable result of studying the constituents of rocks without regard to the origin of these constituents. A very little of the original globulitic base was found unchanged in some of the feldspars. Numerous microlites extend through the groundmass that belong apparently to apatite. This is probably from the same dike that No. 1110 of Mr. Brooks's collection, described by Dr. Wichmann, was obtained.* The "long, small rod-like crystals" in which the plagioclase is said to occur is the usual ledge form which belongs to basaltic plagioclase. The "inserted substance, which has not been individualized," is doubtless the altered globulitic base. No biotite or hematite were seen in No. 329, which was selected with direct reference to procuring as unaltered a specimen as possible, as well as one removed from the influence of the ore and jasper (342) through which the melaphyr cuts. A section showing the junction of the two rocks (342) was made. The melaphyr here becomes a dense black opaque mass, containing a few ledge-formed plagioclase crystals and some decomposed (viriditic) augite. This part is probably an altered tachylitic glass, such as occurrs in similar positions in basalts. The junction with the jasper is well marked, and more regular than one would expect to find it. The globulitic structure shows well in the melaphyr at this immediate line of contact. The "jasper" is composed here of quartz and magnetite. The quartz is in part fine granular, and filled with magnetic dust; while the remainder is coarsely granular, having the same structure as the granite (greisen) southwest of Republic Mountain (No. 128, p. 53). These quartz grains were formed by the fissuring of a quartz mass, not built up of detrital quartz grains, as is the case with a true quartzite according to the definition employed by us. The quartz contained numerous fluid and stone inclusions, as well as microlites, magnetite, and lenticular scales of probable muscovite.

The "diorite" (334, 335) cutting the magnetite yielded specimens showing a well-defined contact (337, 338, 339). No. 335 is a greenish-gray rock composed of hornblende, holding patches of quartz, which contains crystals of tourmaline. The rock holds an abundance of magnetite, in part at least torn from the ore through which it passed. The quartz contains fluid and other inclusions. The schist at this locality is an argillaceous one (340) resembling that found at Republic Mountain, Ishpeming, and Negaunee; but it has been so affected in places by the combined action of the magnetite and other dikes that it has become an ottrelite schist (336). This rock has a dark gray groundmass, holding crystals of ottrelite and minute ones of tourmaline. In the thin section the groundmass is of a clear grayish-white color, and holds ottrelite, tourmaline, and magnetite. This groundmass is composed of a clear talc-like mineral in flakes and scales, apparently orthorhombic. In it occur magnetite grains and irregular masses of this mineral, as well as greenish micaceous scales. The ottrelite in the section is of a green color, shows dichroism, varying from a light to dark green, and contains scales of the talc-like mineral, magnetite, etc. In polarized light it shows a banding generally of lighter and darker shades of the same color. Its edges are broken, step-like, and irregular; and it shows cleavage parallel to the basal and lateral planes. In microscopic characters it and the masonite of Warwick, R. I., are closely alike. The tourmaline is in elongated crystals containing grains of magnetite. All the minerals in this rock are of later origin than the magnetite.

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* Geol. of Wisc., III. 625.

South of the Champion mine dikes of diabase (346) and "diorite" (345) occur in the granite and gneiss. A "diorite" that was undistinguishable from that in the gneiss (345) was found at the east end of the Champion mine, in the "Huronian." This "diorite" contains patches of quartz, which hold crystals of tourmaline in radiated groups. The "diorite" (345), running north and south in the "Laurentian," cuts both the granite and the gneiss, and is composed of hornblende, biotite, quartz, and magnetite. Traces of some of the larger and more porphyritic feldspar crystals remain in a kaolinized mass, containing flakes of biotite and grains of quartz. Were the origin of this rock unknown, it would pass for a sedimentary hornblende schist, so far as the section informs us of its nature. The diabase (346) is comparatively fresh, and is undistinguishable from the diabases seen in the "Huronian." It is composed of augite, plagioclase, a little orthoclase and quartz, magnetite, viridite, and some decomposed olivine.

Another dike (343), cutting the gneiss at this locality, is seen to be composed of hornblende, quartz, feldspar, and magnetite.

On the northerly side of Republic Mountain a garnetiferous "diorite"

(91, 92) was observed cutting across the iron-bearing rocks, bending and breaking them at the junction between the two. The "diorite" holds fragments of the iron-bearing rocks in it, and cuts very irregularly through the schists. Its intrusive character is distinctly marked by the relation which it holds to the country rock. It renders the rock adjacent to it magnetic for a little distance from the junction. A section taken from a specimen (92) free from garnets is seen now to be composed almost, if not entirely, of secondary minerals, — a confused aggregation of greenish hornblende, orthoclase, quartz, and biotite, with traces of magnetic iron. The character of the hornblende is the same as that seen to occur in those rocks whose hornblende is derived from the augite by alteration.

To the southeast of this locality, not far from the granite, the iron-bearing rocks were again found in contact with a similar garnetiferous "dioritic" dike; the former being much contorted and broken, the iron being also magnetic near the contact. A tongue of the "diorite" penetrated the ferruginous rock, and the relations were such that it was evident that the contortion was owing to the intrusion of the "diorite." The "diorite" (121) marked on Mr. Brooks's map of Republic Mountain, lying between the quartzite and Smith's Bay, is seen under the microscope to be very much altered, and composed of hornblende, biotite, plagioclase, orthoclase, quartz, and magnetite, with a little hematite. Of these minerals, it would seem from their structure and relations, that only the magnetite and part of the feldspar were original constituents.

The basic intrusive rocks mentioned in the preceding pages have, in general, been regarded as diorite, Mr. A. A. Julien especially doubting the presence of any diabase in the region.* They would pass, according to the ordinary definitions, macroscopically and microscopically, for diorite, quartz diorite, diabase, chlorite schist, hornblende schist, etc., yet we regard them all simply as more or less altered forms, according to age and conditions, of rocks that were originally the same in origin, structure, composition, and name, — basalt. Of course, the supposed altered andesite (p. 38) would be an exception. The reasons for so regarding them have been briefly pointed out in this and preceding papers.† Excepting the melaphyr of the New Washington mine, we regard them all, then, as the alteration form of basalt known as diabase.

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* Geol. of Mich., II. 42, 193.

† Proc. Boston Soc. Nat. Hist., XIX. 217–237, 309–316; Bull. Mus. Comp. Zoölogy, Cambridge, V. 275–287.

At Republic Mountain, on the southwest side, a garnetiferous "diorite" was seen in direct contact with the jasper, which was much twisted and contorted. The ore associated with the jasper was magnetic. The "diorite" was found to be intrusive here and elsewhere about Republic Mountain, breaking through and uplifting the overlying rock, whose laminæ it is seen to cut obliquely. It also sends stringers and dikes into the schist and jasper. As the "diorite" passed approximately along the lamination of the schists, and is foliated parallel to its walls, it is easy to see how those who believed that, if a rock was "striped," it was *prima facie* evidence that it was a sedimentary one, should overlook the eruptive characters. Most of the "diorites" here contain garnets, this mineral being found principally along the edges of the intrusion, while the centre was nearly, if not entirely, free from it. The schist, in like manner, near the "diorite," also frequently contains garnets, both rocks appearing to have mutually reacted upon each other. Under the microscope, one of these "diorites" (124) is seen to be composed of actinolite, garnet, quartz, and biotite. The arrangement, form, and relations of these indicate that none of them are original constituents of the rock, but all are the products of alteration.

A dike of dark micaceous "diorite" (123), some ten inches in width, was seen near this place, which contained garnet crystals varying from one half an inch to two inches in diameter, averaging about three fourths of an inch. These garnets, like the others observed, are dodecahedrons. Microscopically it is seen to be composed of biotite, quartz, feldspar, and magnetite (?) with the enclosed garnet crystals. The black grains have the microscopic characters of magnetite, although the powder is not magnetic. The biotite is the predominating mineral, and all the present constituents, except, perhaps, the supposed magnetite, appear to be secondary products. The garnet is filled with the magnetite (?). These black inclusions, so far as we are aware, have been taken for magnetite,* except some observed by Professor Pumpelly.† In polarized light the garnet is seen to contain abundantly the same grains of quartz and feldspar that the groundmass does; it also holds some biotite.

The "magnetic siliceous schist" of Mr. Brooks (126) near the granite (128, 129, 130) southwest of Republic Mountain (p. 53), is seen microscopically to be composed of actinolite, hornblende, magnetite, and garnet. The two first form the major portion of the section. The garnet is filled with needles of actinolite. Southeast of Republic Mountain, the same rock (No. 100, p. 53) contains longer and better formed crystals of actinolite. Besides actinolite, the chief constituent, it also contains magnetite, garnet, and a little hematite. The garnet contains inclusions of actinolite. The garnetiferous rock (97) adjacent to the granite (p. 52) is composed of actinolite, quartz, garnet, and a little secondary hematite.

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* Geology of Wisc., III. 608.

† Am. Jour. Sci., (3,) X. 20.

Southeast of the Old Washington mine a dike was seen breaking irregularly through the schists. Near the centre of the dike, the rock (305) resembles a chlorite schist, but is composed of actinolite, magnetite, quartz, biotite, and muscovite, none of which appear to be original constituents, except perhaps the magnetite. A specimen near the exterior (306) was more massive, but contained the same minerals. Part of the iron showed the decomposition of titaniferous iron. No. 307, from the edge of the dike, closely resembles a chlorite schist, and contains garnets and well-formed crystals of tourmaline. No. 308 comes from the edge of the dike, and is so filled with garnets as to resemble eklogite. Neither of the four specimens would macroscopically be taken as belonging to the same rock if their relation was not known. This is probably the rock described by Dr. Wichmann as eklogite.* The schist at the point of contact is much indurated and quartzose, and the garnets make an irregular columnar mass adjacent to it (309). They are so crowded and drawn out at right angles to the schist that their structure very closely simulates the prismatic structure of a basaltic dike. Such structure and arrangement of minerals, in a ring, parallel to the surface of the enclosed fragment, is frequently seen about quartz grains and other foreign materials included in the volcanic rocks of the Cordilleras. Several other dikes of the same rock were seen near this. All were very much contorted, breaking very irregularly through the schist, and showing intrusive characters.

The actinolite schist south of Humboldt was seen to pass into a quartzose rock made up principally of alternate layers of quartz and actinolite (319, 320). This shows very conclusively the sedimentary origin of the schist here. The banded magnetic schist of Mr. Brooks southeast ot the Champion mine (No. 348, p. 57) is seen microscopically to be composed of a thick mat of actinolite holding garnet, quartz, and magnetite. The magnetite is surrounded in many cases by thin films of hematite, derived from the magnetite, and extending between the actinolite crystals. The same hematite films extend around the garnet and penetrate along its fissures, giving it a deep red color, but leaving the centre often clear. Only a little quartz was observed.

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* No. 1091, Geol. of Wisc., III. 649.

These garnet-bearing, actinolite, intrusive rocks we cannot at present definitely place in that position which seems to us proper. In order to do that, it is necessary to have part at least of the original structure or constituents preserved; this we did not find. So far as we can judge, they are probably altered basalts or andesites, most probably the former; this conclusion is, however, liable to be overthrown by new evidence at any time. The reason for this decision is in the main their relation in minerals, position, and structure to the other highly altered "diorites," especially at Republic Mountain. The actinolite schists were in all probability formed from detritus of the same composition as the dikes, and therefore under like conditions are mineralogically about the same.

In the Lake Superior mine, a banded greenish quartz rock resembling prase was observed. In the thin section it is seen to be composed of quartz containing magnetite and innumerable little scales of greenish mica. The green color is due to the latter. Some fluidal inclusions were observed. The quartz shows the granular aggregate polarization observed in connection with the devitrification or alteration quartz in rhyolites and felsites. The relation of this rock to the ore and jasper was that of an intruding, fracturing, uplifting mass, breaking across the lamination but not reaching the surface. Above and adjacent to it in the disturbed jasper and ore "soft hematite" was found. This rock, we think, would make a very pretty object when polished.

The "Soft Hematites."

One of the best localities that we have seen to study the formation of the "soft hematite" is at the Salisbury mine, Ishpeming, just south of the Lake Angeline mine. A "diorite" hill lies between the two mines, which, when erupted, we believe upheaved the jasper and hematite lying on both sides of it. At the west end, on the north side of the hill, the Lake Angeline mine is situated, and it is still an open question whether the ore formation does or does not extend eastward along the flanks of the hill. On the southern side, towards the northern end of the hill, the Salisbury mine is located. This is a "soft hematite," which is held by Mr. Brooks to belong to a different formation, in general, from the hematite. We regard it as the same formation as the jasper and its associated ore, but which has been acted upon by thermal waters. All the writers on the "soft hematites" of this district have regarded them as formed from the decomposition of ferruginous schists by thermal waters, and on this point we are in accord. In general they regard them as peculiar to certain formations making a bed or set of beds in the stratigraphical series below the ore formation proper, while we regard them simply as local modifications of the ore formation of the region occurring under certain conditions; i. e. the conditions that led to the shattering of the rock and gave the opportunity for the formation of thermal springs. On one side of the Salisbury mine is the "diorite," while on the other comes a strong dike of diabase (p. 42). The "diorite" runs about east and west, while the strike of the diabase is about N. 50° E. The latter is seen to be the younger rock, and the marks of its passage through the "diorite" hill can be seen a long distance off. The relation of the two rocks is shown in the plan (Fig. 23), while the supposed relation of the "diorite" to the schist and ore is given in Figure 24.

The Salisbury mine is located in the acute angle *a*, formed by the two intrusives, at the point where the fracturing, breaking, and shattering of the prior or ore formation was greatest, and where hot springs would then most likely occur. The general structure of this region, the character of the ore and its associated kaolin, all confirm, in our mind, this view. As the ore deposit formed under such conditions is necessarily limited, it has become a matter of great importance to the company working this mine to find a continuation of this ore, or a new locality, before the old is completely worked out. The mining captain informed me that the State Geologist, Dr. Rominger, in conformity with his views and those of Messrs. Brooks, Kimball, and others, that the diorite, diabase, jasper, hematite, and limonite are distinct sedimentary formations, advocated the sinking of pits at the points *b*, *c*, *d*, where the formation would, by its foldings, again be brought up, and give the same ore. The point *b* is located at the obtuse angle of the junction of the diabase and diorite, therefore we should not expect so much shattering of the rock, nor so great likelihood of thermal springs. "Soft hematite" would be expected to occur to some extent, but with too much of the undecomposed jaspery rock to make it profitable mining. Such was found to be the case; therefore the theory of Messrs. Rominger, Brooks, and others failed here. If the Lake Angeline ore formation extends east along the northerly side of the "diorite" hill, the most likely place to find a deposit of "soft hematite," if our views are correct, would be at the point *h*, in the acute angle formed by the diabase with the "diorite," as it breaks through the latter. Unfortunately this point is not on the property of the Salisbury mine, and it slumbers in its primeval mud.

The McComber mine, Negaunee, is a mine of "soft hematite"; this, in connection with others lying along the same line, is near the "diorite." Part of these mines, however, lie between two hills of the "diorite." Two deposits occur on the McComber property, separated by a dike of the "diorite." The ore here, like that in the Salisbury mine, seems to occur only where the rocks have been shattered and acted upon by water. The jasper has decomposed (244+), yielding a hydrous silicate of alumina (Kaolin, Brush) (245+, 246+), quartz, hydrous and anhydrous oxide of iron, etc. The minerals associated with the ore are evidently water deposits, — barite (253), rhodochrosite (249+, 250+, 251+, 252+), manganite (247+, 248+), etc. Figure 25 shows the formation of the ore under a jasper cap, the water working in by the means of fissures on both sides.

The Pendill mine, worked for a similar ore, contains much botryoidal limonite (254). In one part the ore was worked out upon the top and sides of an oven-shaped mass, the ore following the curvature of the oven. This is similar to a form observed in the Lake Superior mine, associated likewise with limonite. In the Jackson mine "soft hematite" occurs in places, and it is seen to be associated with and to pass directly into the jasper and "hard ore," showing that they were originally the same. Water-deposited quartz (vein-stone) was found in places in this "soft ore," and a specimen was taken for microscopic examination (276), for the purpose of seeing whether it contained fluid cavities or not. It is found to be full of inclusions, most of which contain bubbles. These bubbles were, in the majority of cases, seen to exhibit motion of greater or less rapidity. Some were seen containing double inclusions, and vapor cavities were observed. All would indicate that the water by which the quartz was deposited was at a higher temperature than the rock has at present. This then would seem to confirm the views of all the writers quoted, as well as of ourselves, that these ores are derived from the decomposition of the ferruginous, siliceous rocks. That this is the correct view of their origin it would seem Dr. Hunt denies.*

The various soft ores are partly true hematites and partly limonites, mixed with more or less impurities, but of course, in general, have none of the characters of an ordinary bog-iron ore.

Our theory, of course, depends upon the relation of the "diorites" to the jasper and ore, which near Ishpeming and Negaunee is somewhat uncertain; yet there is but little doubt that the "diorite" is the later. The dip of the jasper increases as it approaches the "diorite," sometimes standing nearly vertical. It was not observed in contact with the "diorite," but we feel that the constant uptilting of the jasper and associated schists when near these intrusive rocks is good evidence that the "diorite" eruption was later than that of the jasper. The uptilting of the jasper was well seen on a hill north of the Jackson mine, where it was found, standing nearly vertical, within one hundred feet of the "diorite."

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* Geol. of Wisc., III. 660.

Granite, Gneiss, and Quartzite.

The relation of the granite and its associated foliated rocks to the schists of the Iron district is a problem of great geological importance. The diverse views have been given on preceding pages, and it is not necessary to repeat them here. The first-mentioned rocks have been accepted by the Canadian geologists (in part at least), as well as by most American ones, as the direct equivalents of the Laurentian formation of Canada, while the latter is in the same way accepted as the equivalent of the Huronian. Without going into the question of the expediency or right of establishing geological ages upon any other basis than that of organic remains, it is a fair question of inquiry whether the "Laurentian" of Lake Superior is older or younger than the "Huronian." Whose observations were the nearest correct, — those who claim that the granite is intrusive in the schists, or those who hold that it unconformably underlies them? On one side we have the statement of direct intrusive contact; on the other, the evidence afforded by the fact that the strike and dip of the foliation of the two rocks are unlike, the two formations never having been seen in contact.

It is now time to give the facts observed by us.

North of Republic, by the side of the railroad, a few rods from the depot, the granite (82) (Laurentian of Brooks) shows its intrusive character by its containing fragments of schist (83) in it, and by its cutting the main body of schist. These schists are micaceous, hornblendic, and chloritic, with a nearly north and south strike, the foliation of the granite coinciding with it. Northwest of the track, near the above-mentioned locality, the inclusions in the granite are well marked, the foliation of the granite striking S. 20° E. Southeast of Republic Mountain, separated from the supposed "Huronian" by a narrow ravine, the granite was observed in contact with a garnetiferous actinolite rock, beautifully banded and contorted (No. 97, p. 48). While this appears to us to be identical with the "Huronian" rocks, a few rods away, resembling the actinolite schists of Wichmann (100, p. 47), Mr. Brooks believes* it to be "Laurentian," for no reason that we can see except that it is associated with the granite. This rock has been tilted and contorted by the granite which is found in contact with it. The line of junction and the manner of contact show that the granite was the later rock and an eruptive one. The foliation of the granite is parallel to the plane of contact, or at right angles to the pressure. It contains fragments of schist (98), while some highly quartzose schists or quartzites (99) were seen within a few feet of it. These rocks were apparently older than the granites, and had been affected by them. On the southwest side of Republic Mountain the granite was seen about one rod from the "Huronian" schists. This is probably the locality figured by Mr. Brooks,† but the foliation of both appeared to us to be conformable in this way: the schists appeared to have been partially uptilted by the granite, which seemed to have been extravasated obliquely out from under them, very much as the peridotite was under the sandstone at Presque Isle. The foliation is parallel to the plane of pressure, and at right angles to that pressure.

The granite near the edge is fine-grained, resembling a quartzite (128), but a little distance away it is coarser and more granitoid (129). Borne upon the face of the granite next to the schists is a plate of rock about two inches thick (130). This is welded closely to the granite, and has been uplifted and altered by it. Its constituents have been drawn out in the direction of the supposed motion of the granite, and resemble in the field the altered garnetiferous "diorite" (123) described on page 47. The rock is micaceous, of a dark gray color, and contains elongated brownish-gray masses resembling altered garnets. Microscopically it is seen to be composed of biotite, muscovite, quartz, and the garnet(?) masses. The last are now composed of a finely fibrous aggregately polarizing material holding quartz grains, magnetite, and apparently hexagonal or orthorhombic opaque disks. Their nature is unknown, but they most probably belong to the margarophyllites.‡ Whether this rock was originally the same as No. 123 cannot be told, although in many respects it closely resembles it. Should it be, the granite there is younger than the "Huronian diorite."

The granite (129) is seen in the thin section to be composed of quartz with some green mica. Not the slightest trace of feldspar was found. The quartz is broken up into grains, which exactly fit to one another without any cementing material. The granular structure arises not from original water-worn grains, but from the fissuring of an originally continuous siliceous mass. The quartz contains fluid cavities, microlites, and little flakes of mica. No. 128, nearer the Huronian, at the edge of the granite, is microscopically seen to be in finer quartz grains. This rock also contains greenish mica, clusters of actinolite crystals, and garnet grains. The quartz grains contained the same inclusions as those in No. 129. Some magnetite was observed. The actinolite crystals were often seen to extend through two or more of the adjacent quartz grains, not having been broken by the process of fissuring the quartz.

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* Geol. of Wisc., III. 661.

† Geol. of Mich., I. 126.

‡ Am. Jour. Sci., (3,) X. 20.

Specimen 130 consists of two parts, — the schist already described, and the granite to which it is welded. This granite is here composed of quartz, biotite, and grains of garnet. The quartz is in the same fissured grains as that in Nos. 128 and 129, and contains microlites, minute crystals of greenish mica, and fluid cavities. The majority of the fluid inclusions lie in the secondary fissures, but part are in the solid quartz. The biotite is seen to frequently extend from one quartz grain into another without having been broken by the fissuring of the quartz. The garnet contains actinolite crystals, and the same black grains that it did in the adjacent schist (130). The biotite and garnet are evidently derived from this schist, and are in fragments. This section, more than either No. 128 or 129, shows the effect of the schist in adding foreign ingredients to the granite, and also the action of the granite on the schist by tearing off and dissolving portions of its material. Such phenomena are the usual accompaniments of the mutual reaction of two rocks when one is intruded through the other. The three sections 128, 129, and 130 well illustrate the differences that can be observed in the same rock within a distance of a few feet.

It seems appropriate to describe with the granites last given the "quartzite" (page 34) of Mr. Brooks at Republic Mountain. The rock (95, 115, 116, 117, 118, 119) is greenish gray, macroscopically containing quartz, actinolite, and epidote. Under the microscope it (115, 118) is seen to contain quartz, actinolite, hornblende, greenish mica, epidote, magnetite, and hematite. The quartz is in similar grains to that in Nos. 128 and 129, and contains numerous microlites and mica inclusions, as well as fluid cavities. This rock, it would seem, belongs to the granites adjacent to Republic Mountain, and is an offshoot from them. In microscopic characters they are closely allied, but we only offer this for what such characters are worth in such questions as these. One thing we know. This ("quartzite") granite is eruptive in its present place, and if it is part of the same formation that the adjacent granites are, then the latter are younger in their present position than the iron ore of Republic Mountain.

The preceding rocks (128, 129, 130) naturally fall under the name of *greisen*, but as they seem simply to be the modified edge of the "Laurentian" granite, we prefer to apply the name *granite* to them. The practice of giving a different name to every little local modification in rocks has been a constant source of confusion in lithology. This practice has perhaps never been carried to greater extent than it has been in this district.*

South of Ishpeming, on the line of the Chicago and Northwestern Railroad, a gray gneiss (192, 193) was seen dipping W. 33°, cut by the common reddish granite (194), which sends veins through it. Figure 26 was taken here from the side of a little cliff (195). The gneiss, at the points in which it is cut by the granite, is less schistose, and becomes more granitoid in its structure. A few rods west, on the north side of the railroad track, this granite is seen in contact (197) with and cutting a quartzite that resembles the ordinary "Huronian" quartzites. The granite is here in large masses, but shows its intrusive character when in contact with the gneiss, quartzite, or schists. About one eighth of a mile nearer Ishpeming the granite (202) was seen in contact (200) with and contorting schists (201, 203). This shows its intrusive character on both sides of the schist, the contact being well marked in many places. On the same elevation a fine-grained granite (204) was seen to be intrusive in a dark green nodular schist, containing large irregular masses of feldspar (205). These schists and granites are in the area mapped as "Huronian" by Mr. Brooks.

The granite breaking through the "diorite" at Picnic Point has been referred to (page 39). This appears to be the same as the reddish granite that occurs at the mouth of Dead River (62, 63). The lamination of this latter granite strikes S. 80° E. The reddish granite of the entire region appears to be lithologically the same. That breaking through the "diorite" at Picnic Point (56) is seen to be, under the microscope, a crystalline aggregate of feldspar, quartz, and hornblende, with magnetite. The feldspar is in part clear orthoclase, but mostly a pinkish decomposed one without definite polarization. This, according to the present imperfect method of microscopic analysis, is presumably orthoclase, but we believe it may or may not be so. This feldspar is now composed of a fibrous decomposition product, kaolin (?), with ox-

* See Geol. of Mich., Vol. II.

ide of iron and quartz. Contrary to the views of Dr. Wichmann and Prof. Zirkel, we regard these as the products of decomposition of the feldspar and its enclosed foreign materials, and not originally formed products. Likewise we find the same alteration products in distinguishable plagioclase as well as in orthoclase.* The quartz occurring in the feldspar appears to be a secondary product, as also is part of that occurring independently in the rock. Many minute microlites occur in the decomposed portion of the feldspar as a secondary product. The quartz contains fluid cavities and microlites. No salt cubes were seen in the fluid inclusions. It will be remembered that Mr. Charles E. Wright pointed out that what he supposed to be the younger "Huronian" granite contained such cubes in the fluid inclusions, while the "Laurentian" granite did not. Here we have an eruptive granite in a district mapped as "Huronian" that so far reveals no salt cubes. Of course, the evidence is negative; in another section, or possibly in some overlooked portion of this section, they might be found. So long as Mr. Wright has used this as a means of diagnosis, we point to the results here simply for what they are worth to those who rely upon microscopic analysis only. The hornblende is of a green color, and is broken and torn. Considerable magnetite, pyrite, and secondary hematite was seen. Some minute crystals and grains, supposed to be zircons, were also observed, as well as secondary epidote. Titanite is quite abundant. The granite† at the mouth of Dead River (62, 63) is seen microscopically to be similar to the one just described (56). Its feldspar is not so much decomposed, and the orthoclase and plagioclase are readily distinguishable, the latter being quite abundant. The hornblende has been almost entirely altered to chlorite and biotite (?). The quartz contains microlites and fluid and vapor cavities. Some minute crystals of zircon were seen in the feldspar as well as in the quartz. The decomposed feldspar is almost filled with microlites. Epidote is abundant as a secondary product. The rock also contains magnetite.

Specimen 82 (p. 52) is a pinkish-gray granite. Under the microscope it is seen to be composed of orthoclase, plagioclase, quartz, biotite, muscovite, and magnetite. The feldspar is fresher than in the preceding granites, and contains numerous mica inclusions, mostly muscovite. The quartz holds microlites and both glass and stone cavities. The muscovite generally cuts through or is mortised into the biotite, the same as the feldspar is in the augite of the diabases. The muscovite is quite subordinate to the biotite, and the plagioclase to the orthoclase. The red granite south of Ishpeming (No. 194, p. 55) is composed of orthoclase, plagioclase, quartz, viridite, magnetite, and hematite. The feldspar is somewhat altered, the plagioclase showing the same microlites and hematite alteration products as the orthoclase. Part of the feldspar shows very beautifully the polarization characters of microcline. The original mica in the rock is now altered to a viriditic material. The quartz contains inclusions of feldspar, biotite, microlites, magnetite, and fluid, vapor, glass, and stone cavities. The gneiss, in which this last granite is eruptive, is a dark gray foliated rock (192, 193) composed of biotite, quartz, orthoclase, plagioclase, magnetite, and a little pyrite. The feldspar is much decomposed, and contains microlites, as well as the lenticular, colorless foliæ, so common in the decomposed feldspars in the granites of this region, which we suppose belong to muscovite. The quartz contains the same little disks, as well as fluid and vapor cavities. Numerous microlites of apatite, as well as some grains that may belong to zircon, occur in the rock. The characters of the rock appear rather to be those of an eruptive than of a sedimentary one; but as its relations to anything older than itself were not determined, nothing definite can be said upon this point. In a section made of an intrusion of the granite through the gneiss (195), both show their respective characters as given above.

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* Geol. of Wisc., III. 601.

† Chloritic gneiss of Brooks. Geol. of Wisc., III. 662.

One half-mile southwest of Humboldt the granite is intrusive in a mica schist. The granite at this point is white, and not of the usual pinkish color. Southeast of the Old Washington mine the pinkish granite (323) was found intrusive in a hornblendic gneiss. We have termed these rocks granite because the foliation appears to be a fluidal structure parallel to the contact planes, and because they pass into regularly non-foliated granites at a distance from their junction with the schists.

Southeast of the Champion mine the granite (350, 351) is found intrusive in a schist (349, 352, 353, 354). The schist is indurated and much changed where the intrusive tongues of granite enter it (347). There can be no question that the granite is intrusive, and younger than the schists. They have both been mapped by Mr. Brooks as "Laurentian." Four hundred feet east occur his Huronian magnetic schists (348), having exactly the same strike and dip as the schists in contact with the granite. Furthermore, if we could prolong the magnetic schists in the line of their strike, so far as we could ascertain, the non-magnetic schists would be included directly in them as a component part. The difference now between the two rocks is perhaps due to the action of the granite upon the schist. Microscopically this schist (353) is composed of biotite, quartz, magnetite, and a muscovite-like mineral. The quartz contains inclusions of the other minerals, and fluid cavities with bubbles in exceedingly active motion compared with the usual rate of movement. The fluid cavities are not numerous. The part filled with quartz and the muscovite-like mineral appears to be a portion of the original fine sediment (mud) that held the coarser material. The alteration and crystallization of this argillaceous detritus give with the original quartz grains the present texture, approaching closely a gneiss.

East of the same mine the gneiss (344) was found dipping N. 60° W. 67°, and is finely foliated. This gneiss is cut through by intrusive granite, and by dikes of diabase and "diorite" (343, 345, 346). The latter cut the granite as well as the gneiss. (See page 45.) The gneiss is composed of biotite, quartz, and the same muscovite-like mineral as the schist, No. 353, which in fact it closely resembles. The quartz contains microlites, scales, and grains of the other minerals and fluid cavities. The same decomposed material cementing the quartz grains is found in this as in the schist. So far as we can tell by microscopic observation, we regard this rock as sedimentary, and perhaps only a more highly metamorphosed condition of the adjacent schist. As its relations to any rock older than itself were not observed, of course no definite statement can be made. The supposed sedimentary material forming the cement and the base out of which the mica, in part at least, has crystallized, can arise from the decomposition of feldspar crystals in their original position, and a material undistinguishable from it is seen frequently to have been formed thus in eruptive rocks. We base our conclusion that the rock is sedimentary upon the general structure of the rock, especially upon the form and relations of the quartz grains to the rest of the constituents.

The term quartzite is, we believe, when employed in its proper use, restricted to an indurated sandstone, and in this sense we employ it. We believe this to be more in accordance with the generally accepted use of the term, although, in practice, Messrs. Zirkel, Lasaulx, Hawes (a pupil of Lasaulx), and other lithologists, employ it also to designate quartz veinstones and other forms of chemically deposited quartz. Dr. Wichmann, it would seem, employed it only for rocks which have no interstitial or cementing substance remaining uncrystallized between the quartz grains. He classes them under the head of non-fragmental rocks, saying that his other class comprises all those "which have been formed mechanically out of the materials of older rocks," yet he describes a quartzite that he regards as having been a fragmental rock. In fact, his lines between fragmental and non-fragmental rocks seem to have been drawn from the realms of fancy, as a large proportion of his non-fragmental rocks are evidently, both from field and microscopic characters, as truly sedimentary as those classed as fragmental ones. If we understand Dr. Wichmann aright, we presume that the St. Peters sandstone when indurated, as we have frequently seen it, would form a quartzite, while the Potsdam sandstone, if it were indurated in like manner, would form a — sandstone, unless some of it had its cementing material entirely crystallized.*

The reddish and grayish quartzite, near the northern railroad track west of Ishpeming, is composed of quartz in rounded grains held by a chloritic cementing material. Considerable hematite was observed as a decomposition product. The quartz contains microlites, trichites, and fluid cavities. The quartzite forming the *fallen* wall of the New York mine (186) is a very dark greenish-gray rock, composed of rounded grains of quartz, and crystals and fragments of magnetite cemented by a chloritic material. The interstitial substance in this appears to have been entirely changed to chlorite. The quartz contains microlites, trichites, and fluid inclusions more abundantly than the rock last mentioned. A fragment of jasper was observed in this rock. Another specimen of the same rock (187) is composed of macroscopically evident fragments of jasper and magnetite, and quartz grains. Under the microscope the section was seen to be composed of quartz, jasper, magnetite, and chlorite. The quartz has the same inclusions, but part of the microlites appear to be zircon. These rocks, as we have before pointed out, were evidently derived from the underlying ore-bed (page 30).

The quartzite (197, 198) found to be older than the intrusive "Laurentian" granite (page 55) is a dark gray rock composed of quartz grains, biotite, and fibrous microlitic cementing material. The quartz contains fluid inclusions and little crystals of zircon. The crystals of zircon are the same as those observed in the gneiss in that vicinity (193), and it is not improbable that the quartzite is derived from it. In this case the order of succession is, 1st, the gneiss; 2d, the quartzite; 3d, the eruptive red granite (gneiss of Mr. Brooks).

The quartzite overlying the ore at the north pit of the Jackson mine at Negaunee is made up of the ruins of the underlying ore. It is composed of quartz, jasper, magnetite, hematite, and a fibrous microlitic interstitial material. The quartz contains microlites and fluid inclusions.

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* Geol. of Wisc., III. 613, 615, 649, 655.

The rock through which the "diorite" (page 43, No. 232) passes, is a highly indurated feldspathic sandstone (233), in which the feldspar predominates greatly over the quartz. It has a greenish, compact, felsitic base, holding grains of quartz. This would easily pass for a quartz porphyry or felsite, with those who advocate the passage of sedimentary rocks into felsite. It is best classified as a *porodite.*[*] Microscopically it is seen to be composed of fragments of feldspar with some quartz grains. The feldspar is decomposed greatly, forming micaceous scales, but shows in some cases its triclinic character. It was most probably formed from the detritus of a granite.

Potsdam Sandstone.

The sandstones at Marquette resting upon the azoic schists are in the upper portions fine-grained (14, 15), but below they become conglomeritic. The coarser sandstone (12 A, 13) is composed principally of quartz and feldspar; the feldspar is the pinkish variety belonging to the azoic granites in the vicinity. Many of the quartz grains are seen to be crystals with unworn facets; it is therefore probable that they came from veins, and the sandstone making was quite rapid. The other sources of the quartz were probably the granites and quartzites underlying them. Coarse pebbles occur in portions of the rock belonging to the adjacent formations: quartzite, ferruginous quartzite, argillite, chlorite, "diorite," etc. (16, 17, 18, 19, 20, 21, 22, 23, 24, 25). The inclosed pebbles were evidently when deposited nearly, if not quite, in the same condition as they and the rocks from which they were derived are to-day; as was pointed out by Foster and Whitney. South of the Carp River, in the locality figured by Messrs. Foster and Whitney, the sandstone strata are seen to abut against and overlie the vertical edges of the quartzite (29, 30, 31, 32, 33, 34). The dip was about S. 20° W. 16° to 18°. The Sandstone at Presque Isle contains the same materials as that south of Marquette, but has suffered a local modification described in connection with the peridotite of that point; — to which we now pass.

Peridotite and Serpentine.

The chief rock at Presque Isle, north of Dead River, is a peridotic one, composed of olivine, enstatite, and diallage, which is the composition of lherzolite. In places, this rock is much altered, forming a serpentine (65, 66, 67, 68, 69, 70, 71, 72, 73, 74). We find every gradation, from the rock only partly altered to that which is so completely changed to serpentine that only traces of the enstatite, diallage, and olivine remain.

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[*] Bull. Mus. Comp. Zoölogy, V. 280.

Under the microscope, the rock (65) is seen to be made up of rounded grains and crystals of olivine, held in and often completely surrounded by the enstatite and diallage. These minerals evidently crystallized later than the olivine, and play the same *rôle* here that the augite does in diabase, the glass in basalt, and quartz in granite. The olivine is traversed by fissures, along which the usual serpentinous alteration has taken place. In many, the alteration is confined to the vicinity of the fissures and the periphery of the olivine, but others are changed throughout. Much black dust comes in the altered portions (magnetite?), as a residue left over in the decomposition of the olivine and the formation of the serpentine. In many cases this black residuum forms a rectangular or irregular network or grating throughout the changed olivine. The enstatite is altered along the cleavage planes and network of fissures by which it is traversed. It does not become changed to the serpentine so readily as the olivine. All contain inclusions of black octahedral crystals that are presumably magnetite, as the powder is magnetic, and no trace of chromic oxide was found by chemical tests. Besides the serpentine, there occur, as other alteration products, feldspar (?), viridite, and dolomite (?). The hand specimen (65) is a grayish black (almost black) rock, showing under the glass a little serpentine, enstatite, and magnetite. It weathers somewhat brownish.

In other specimens from the same rock, but more altered, we only find traces of the original structure. The formation of the serpentine along the fissures, and the network of magnetite, usually are well marked after the enstatite, diallage, and olivine are entirely altered. The serpentine, unless it suffer alteration itself, generally shows under the microscope its original structure, as it was formed along the fissures. One section (71) shows simply greenish pseudomorphs after olivine enclosed in a carbonate, presumably dolomite. Another section (74) is composed now of serpentine and magnetite, and, if it were not absolutely known whence it came, its derivation could only be told by the arrangement of the magnetite. Certain of the specimens are largely composed of the dolomite observed in No. 71, and microscopic as well as field examination renders it most probable that Dr. Rominger's stratified dolomite (72) is simply a more highly altered portion of the peridotite. No. 71 came from the east side and out of the same upper formation as No. 72. This is a reddish brown and greenish serpentine, traversed by a fine network of dolomitic veins. The microscopic characters of the decomposed peridotite were given to some extent by Dr. Wichmann, who, it would seem, had only the serpentine, under which name he describes the rock.*

The geological history of this rock is very interesting. Dr. Houghton thought that it was an eruptive rock, and younger than the sandstone which was uplifted by it, believing it to be a greenstone impregnated with serpentine. He states that, near the line of junction, the sedimentary rock has been greatly shattered, and its fissures filled with injections of calcareous matter. Dr. John Locke thought the "light green trap" was interfused with the sandstone at this point.

Messrs Foster and Whitney considered that the rock was an immense consolidated lava flow, although it wanted the vesicular structure, while the part filled with the white veins was regarded as a volcanic sand or ash deposited on the lava stream. Younger than this azoic lava was the sandstone deposited upon it (Potsdam). Chemical analysis was given of it, but no name assigned to the rock. Later, this was regarded as closely related to serpentine by Professor Whitney, who gave three analyses of it.† Later, Dr. Hunt, accepting Professor Whitney's analyses, regarded this rock as a somewhat impure sedimentary serpentine belonging to the Huronian series.

Dr. Rominger later regarded this rock as a half-decomposed basalt or highly ferruginous serpentine; the part filled with the veins was taken to be an older sedimentary rock, a dolomite, upheaved and broken by the trap, and overlaid by the conglomerate and sandstone. This sandstone is supposed to have been deposited in the inequalities of the underlying rock following its contours. He thought it most probable that the sandstone was deposited at its present inclination, although it may have been slightly upheaved since. The conglomerate beds at the base of the sandstone are said to contain numerous fragments of the underlying rock. We regard this peridotite as an eruptive rock, younger than the sandstone overlying it, and agree in this particular with Dr. Houghton. The portion filled with veins, that was taken by him as a sedimentary rock belonging to the sandstone, or a mixture of sandstone and trap; as a volcanic sand or ash, by Messrs. Foster and Whitney; and as a dolomite, older than both the trap and sandstone, by Dr. Rominger,— we regard as simply the upper portion of the intrusive mass modified by its contact while heated with the overlying sandstone, and by the percolating waters since.

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* Geol. of Wisc., III. 619.

† Am. Jour. Sci., 1859, (2,) XXVIII. 18.

As we differ so strikingly in most particulars from the geologists quoted, it is necessary to give our reasons therefor. Only part of a day could be spent at Presque Isle; therefore, many things that ought to have been examined could not be. On the southeastern side, the sandstone dips quite irregularly from twenty to thirty degrees southerly. The strata follow the curve of the underlying peridotite, forming in places anticlinals. The distinction between the sandstone and its underlying rock was everywhere seen by us to be well marked. The surface of the peridotite is in rounded knobs, the whole mass itself in general outline forming one immense knob. The sandstone and conglomerate were examined, and found to conform in their stratification to the contour of the whole mass, having the same waving outline; also, for from two to three feet above the peridotite, they are indurated, changed, and show characters that we regard as evidence of heat action and of hot waters. They are filled with vein and chalcedonic quartz, and hardened and reddened the same as is the sandstone immediately underlying the melaphyr overflows in the Copper district (75, 76, 77, 78, 79). Certain portions have been changed, so that they resemble a volcanic ash, although they are simple ferruginous sandstones (78). Above the limit of baked sandstone and conglomerate comes the unaltered ordinary red sandstone (81). Microscopic sections of the indurated conglomeritic sandstone show that much of the quartz is a secondary water deposit since the deposition of the fragments composing the rock. We searched carefully for the pebbles or fragments of the underlying rock in the conglomerate, which Dr. Rominger states are abundant, but could find none. We have been unable to find either macroscopically or microscopically a single trace, so far, of the peridotite or of its veïned portion (dolomite of Rominger) in the conglomerate or sandstone. The peridotite forms abundant pebbles now upon the beach, which, had the conglomerate been formed upon it, should have been included. The conglomerate and sandstone contain the same material in pebbles, etc. that the sandstone and conglomerate do in the Marquette quarries and near Carp River. Had the sandstone and conglomerate been laid down upon the irregular surface of the peridotite, they should have abutted against its unconformable portions, the same as they do against the quartzite at Carp River; instead of this, the strata conform to the curves of the peridotite, like layers of blankets, forming anticlinals and synclinals. The dip in many places, especially on the southeastern side, is too steep and irregular, while the strata are continuous, to have been formed at that angle by sedimentation. The induration of the sandstone and conglomerate, and of the enclosed pebbles, as well as the deposition of the silica, do not occur where the sandstone has been seen to come in contact with the "Huronian" schists and quartzites. From the above facts we feel that we are justified in dissenting from the views of most of those who have written upon this locality.

At the eastern portion of Presque Isle, either a fault or a protrusion of the peridotite up through the sandstone exists. This locality we were able to examine only a minute or two, on account of an approaching thunder-storm, while we were in a row-boat, but it deserves further careful examination. The best serpentine that we saw upon Presque Isle was observed at this place. In the thin section, the more serpentinous portions of the peridotite are frequently seen to contain dolomite, and fragments effervesce freely in hot hydrochloric acid. The upper portion, supposed to be dolomite by Rominger, extends as a sheet of variable thickness over all the peridotite separating it from the overlying sandstone. This, so far as we can tell, is the upper portion of the peridotite, affected by direct contact with the sandstone, and by the action of hot waters since, at the time the silica was deposited in the conglomerate. This part is filled in with impure dolomitic veins, which, it seems, caused Dr. Rominger to pronounce the rock a dolomite, although the veins have the characters of being secondary water deposits, as they were described by Messrs. Foster and Whitney, and not igneous injections, as they were thought to be by Dr. Houghton. The unmistakable peridotite has in places the same structure. The peridotite is much fissured, breaking up into rounded masses, cemented by segregated serpentine. We regard the peridotite as eruptive, and feel that its field and microscopic characters both point to the same conclusion. The manner of eruption was probably something like the laccolites described by Mr. G. K. Gilbert; on the sides the strata were arched and bent upwards, but on the eastern end either a fault or protrusion exists. This place would afford an excellent chance to study the relations of the sandstone to the peridotite, if the contact of the two can be seen.

If we are right in our observations and conclusions, this locality has an important bearing upon the origin of the serpentine here, showing that it is a metamorphosed eruptive rock, and of younger age than at least some one hundred feet of the sandstone. It further shows that, so far as this is concerned, lithology fails in giving the age of a rock, this having been indorsed as good "Huronian";* also that an eruptive rock may be so changed as to be taken by observers for a sedimentary stratified one, even a good dolomitic limestone. The origin of the serpentinous part by direct change *in situ* of a peridotite (eruptive), as well as by the filling of fissures in the peridotite by serpentinous material derived from the surrounding rock, would seem in the main to be consonant with the observations of Bonney, Becke, Berwerth, Dathe, Doelter, Drasche, Hochstetter, Koch, Lemberg, Sandberger, Streng, Tschermak, Zirkel, and others. Peridotite, which we provisionally classed with gabbro under basalt, in a preliminary publication "On the Classification of Rocks,"[*] it would seem from further and more extended study, should be classed as a distinct species; and some other rocks may possibly belong with it. This species would represent a more basic one than basalt, containing generally between thirty-five and forty-five per cent of silica, or, more nearly, forty to forty-three per cent. The reasons for this view it is intended to give fully in another publication, but they would be out of place here.

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* Mr. Brooks thinks "it is not certain that this is of Huronian age." (Geol. of Wisc., III. 659.)

The following analyses (incomplete) of this peridotite were made and published by Prof. Whitney: —

	I.	II.	III.	IV.
SiO_2	38.24	36.95	37.25	
Al_2O_3	1.48			
Fe^2O_3	34.50	16.50	6.75	12.90
FeO			14.14	19.52
MgO	14.83	33.07	28.67	14.83
CaO	1.42			
Na_2O	Determined with the iron.	.97	1.16	
H_2O	9.53	10.40	10.89	
	100.00		98.86	

Analysis I. is taken from Foster and Whitney's Report on the Geology of Lake Superior, II. 92. Analyses II., III., and IV., from the American Journal of Science, (2,) XXVIII. 18.

Three miles and a half northwest of Ishpeming, or one mile and a half west of Deer Lake, serpentine occurs abundently on the land of Mr. Julius Ropes, postmaster of Ishpeming.[†] This rock, although quite hard, forms very beautiful specimens when polished (234, 235, 236, 237,

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[*] Bull. Mus. Comp. Zoölogy, V. 279.

[†] First Annual Report of the Commissioner of Mineral Statistics of the State of Michigan, pp. 204 – 206.

238, 239, 240, 241, 242, 243, 244, 245, 246). Associated with and comprising probably part of the same formation is a greenish and grayish limestone (247, 248, 249, 250, 251). In one place much chrysotile was seen, which had formerly been regarded as asbestus (252).

No. 235 is a beautiful green serpentine, giving a colorless section holding magnetite. Under the microscope this shows a most beautiful fibrous aggregate polarization. Other sections (241, 242, 243, 245) show a more coarsely fibrous aggregate polarization, and are composed of serpentine and magnetite. The magnetite is seen here to be arranged in the same way that it was in the more decomposed peridotite of Presque Isle, forming a network corresponding to the outlines of the grains and fissures in the olivine, as well as occasionally a network in the altered olivine itself. Although we find no trace of either olivine or enstatite in this serpentine, this structure gives a strong probability that this rock was originally in nature and origin a peridotite. Every microscopic character in this serpentine indicates that it is formed by direct alteration *in situ* from another rock, and, so far as we can now tell, that was an olivine one. Whether this is of the same age and origin as that at Presque Isle or not can only be determined, if at all, by studying its relations to its associated rocks.

General Discussion and Results.

The historical part of this paper we have endeavored to bring down to the date of its completion. As the historical portions of both the Iron and Copper districts were, in the main, written in 1879, the latter material has been added as best it could be done. On March 6, 1880, through the courtesy of Prof. T. C. Chamberlain, Chief Geologist of the Wisconsin Survey, we received an advance copy of that portion of the third volume of his survey publications which gives Dr. Arthur Wichmann's microscopic analyses of some of the rocks in the Iron district and Appendices A and B, or from pages 600 to 663. This detached portion has been referred to repeatedly in the preceding pages, but no connected account was or need be given of it. On April 8 the complete volume was received, but as the preceding portion of our work was, with the exception of a few pages, already prepared for the press, and in part struck off, it became necessary to incorporate all mention of it in this portion of the paper at this date (April 10, 1880).

The observations and figures given in the preceding text show conclusively that the statements of Messrs. Dana, Kimball, Hunt, Brooks, and others, that the iron ore is interstratified in the associated schists, are incorrect, and only return to the view advocated by Mr. Foster in his early publication. So far as geological science has now advanced, the facts observed can only be explained by the eruptive origin of both the ore and jasper, as they make the same formation. The only escape from this conclusion is the supposition that the ore and jasper have been rendered plastic *in situ*, while the chloritic schist has not been. Such a supposition Mr. Brooks was forced in part to adopt.* That the ore and jasper have been thus rendered plastic, while the schists, quartzites, and other associated rocks have not been, is too absurd, chemically or geologically, to be tolerated for a moment as an hypothesis. Should it or any other theory be proved to be correct in actual fact, then it is to be admitted; but when one resorts to theories that are not sound scientifically, merely to escape from a dilemma that a former theory brings him to, he is neither philosophical nor scientific. Theories must conform to facts, not the facts to the theory. We can point out facts whether they can be explained or not, but the theory must conform to our present knowledge. The ore and jasper show that they are the intrusive bodies by their breaking across the lamination of the schists and other rocks, by the changes that take place in the latter at the line of junction, by horses of schist being enclosed in the ore, by the curvature of the lamination produced by the intrusion of the ore and jasper, etc. Not the slightest sign of the plasticity or intrusion of the schists relative to the ore or jasper was seen. That the present lamination of the schist existed prior to the intrusion of the ore and jasper is shown by the effect of the latter upon and its relations to it. That this lamination is the original plane of deposition is for part of the schists not known; but whether it is or not, it has been taken to be such by the observers quoted in the establishment of their theories, and they must abide by it. The lamination, however, coincides with many of the well-stratified rocks adjacent, and in some of these the ore and jasper were unmistakably intrusive. The schists that retained well-marked stratification planes showed in some places extraordinary contortions, one specimen (293) showing a synclinal and anticlinal fold, requiring, were the top eroded, the counting of the same layer four times in the width of two inches. This is only one case out of numerous ones observed (292, 292+, 302). In the fine-grained detritus composing some of the schists it is quite likely true that the lamination does not coincide with the original bedding; but if it does not, then the breaking of the ore across any chosen plane whatsoever, except the lamination plane, can be shown more easily than in the former case.

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* Geol. of Mich., I. 139, 140.

The ore and jasper seem to have been erupted in huge bosses and overflows, as well as intruded into the schist in the form of long arm- and wedge-like masses or sheets. On account of the banded character of the jasper, and the intrusion generally being nearly in line of the lamination in the large mass, they have an apparently stratified character to those who believe any "striped" rock is a sedimentary one; but when examined in detail, and in places where the relations can be seen, they prove to be eruptive. Those who advocate the sedimentary origin only, take the jasper and ore as a whole, and, because it is apparently to them stratified, assume without further question or examination that it is so. We have gone upon the principle, that the relations of rocks to one another show the origin of each one except the oldest, and this must be the arbiter in every case when the other characters are doubtful or are questioned. It happens then that this is largely a question of methods and principles of observation.

The natural work of mining is to obscure or destroy the geological evidences; furthermore, the natural changes that have taken place in the constitution of the rocks, the decomposition, the uplifts, fractures, foldings, and other accidents which they all have suffered, tend to increase the difficulty of finding such proof. Of necessity the characters show best upon the walls of abandoned open pits which the rain had washed clean, but they were also found in the present workings. Likewise they are best studied in comparatively small masses, partly because their relations are easier seen, and partly because the miner generally leaves no others that can be studied. We were enabled, however, to observe the intrusive relations, not only of small masses, but of some containing thousands of tons. The small masses were, however, either seen to be joined, or had been joined until cut off by mining, to the main body. The view that they have been rendered plastic *in situ* is not sustained by the facts, and when we take into consideration the associated rocks is absurd on its face. The facts, then, sustain the views and observations of Messrs. Foster and Whitney, and show that the work of the other observers has been superficial and inaccurate. We are well aware that objections from a metallurgical or chemical standpoint have been raised against the theory of the eruptive origin of hematite and silica together, in such forms as we now find them. If the ore was magnetic at the time of eruption, and has since been altered, this objection is then done away with. The secondary changes that have occurred in the rock since eruption, as shown by microscopic examination, may also help. It is well known that there are facts in every science that it is not able to explain at any one given time; but the facts exist the same, and the science in time rises to meet them. So in this case the fact is they are eruptive, and the burden of chemical explanation rests upon the chemist, not upon us. He must explain it sooner or later, unless he disproves our observations. Crystals of hematite crystallizing from the molten magma of trachytes and rhyolites have long been known, and are described in all the standard works on micro-lithology. These then offer the same problem, and prove that hematite can be crystallized directly out of the same molten magma, and at the same time with the silica and silicates. It is the business of the chemist to meet the facts, and not for us to make the facts conform to his knowledge or theories. It is our business to state what we see and find, and his to explain it if he can, but not to deny it for the simple and sole reason that he cannot cope with it in the present state of his knowledge. The eruptive origin of the iron also has a bearing on the theory that its presence indicated a vast amount of organic life in the "Huronian" epoch.

We have found that a large proportion of the rocks said to be interstratified, and to pass by insensible (or any other) transitions into the adjacent rocks, are eruptive, and do not so pass into the country rock. The assumption that they were stratified was based on their foliation being parallel to their walls, on their being intrusive approximately parallel to the lamination of the schists, their general resemblance to the country rock of similar chemical composition, the inability of the observers to find their lines of junction, and the lack of knowledge of the same observers of the characters of eruptive as well as of sedimentary rocks. Their decision in this, as before, was based on a mere superficial glance over the surface, and the assumption that, because a rock looked as though it was stratified, i. e. had any marks that they thought indicated stratification, it must of necessity be stratified. No effort was made to find out the real relations of the rocks to one another. No attempt was made to see whether one rock was laid down on another as a sedimentary bed, or whether it was an overflow or intrusion. They were "striped" or foliated, jointed or showed cleavage planes, and that was enough; any further observation was superfluous. They assumed that Messrs. Foster and Whitney's work was erroneous without making the necessary observations to prove it so, and the geological world accepted it without question because it agreed with the fashionable theories.

The intrusive rocks belong in general to the basalts, but are of course old, and in the majority of cases greatly altered. One probable andesite as well as intrusive felsites (rhyolites) was discovered. These rocks had never been noted before by the previous observers. One class of the intrusive rocks can be referred to the basalts only with doubt, as the necessary proof of their original composition is thus far wanting, i. e. the actinolite rocks. The evidence is very strong that in the other basic intrusives all the varieties are produced by the alteration of their constituents, and that they were not erupted in their present state.

It is to be noticed that, while we have found olivine abundantly in the diabases, Dr. Wichmann states that "olivine diabase is not present amongst the rocks from the iron region of Lake Superior." *

The "soft hematites" are doubtless produced by the decomposition of the jasper and its ore, brought about by the fracturing of the rocks by the intrusives and by the secondary action of water, presumably hot, on account of the microscopic characters of the quartz deposited by it. Besides the "soft hematites" there occur the quartzites and conglomerates derived from the ore and jasper, as well as the sandstones and schists impregnated by iron, which are sometimes mined to a slight extent.

We have heretofore seen that the view that the "Huronian" unconformably overlies the "Laurentian" has been only supported by the fact that the foliation of the latter did not conform in its dip to the lamination of the former. This proof is of no value unless it can be shown that both rocks are stratified and *in situ.* That the latter is not so, we have seen in numerous localities. Heretofore the two systems have not been observed in contact, but recently statements have been published that their junctions have been seen in other regions.† The statement is made that both rocks are stratified, but no proof is adduced to show on what the conclusion is founded, and, although the contacts were said to show beautifully, nothing was published indicating that the kind and manner of the junction was observed. It would seem that even here the decision concerning the unconformability was based on the foliation only.

So far as the Marquette district is concerned we have shown very much stronger and more abundant evidence to prove that the "Laurentian" granite is younger than the "Huronian," and an eruptive rock, than has been advanced by Mr. Brooks (the only one who has advanced anything called proof) to show that it is older. Further, the inability of the later observers to distinguish the eruptive rocks, even in the "Huronian," detracts from their evidence concerning the "Laurentian." The granite that Mr. Brooks placed as Formation XX. of the "Huronian," merely because that was the easiest way to dispose of it, unless he wished to acknowledge that his "Laurentian" granite or gneiss was intrusive in the "Huronian," bids fair to absorb now all the "Laurentian" region, if we can judge from what Mr. Brooks writes. He says: "Dr. Rominger considers certain granitic and gneissoid rocks north and southwest of Marquette, which I did not study but regarded as Laurentian, to belong to this series. I have but little doubt but that the younger Huronian rock made out in the Menominee region (the granitic bed XX.) will yet be identified in the Marquette region, and will be found to be more or less gneissic. The very rocks mentioned above may possibly be Upper Huronian; the granites, etc., southwest of Michigamme lake very probably are."* Although this granite is in the region mapped as "Laurentian" by Mr. Brooks, he does not tell us how to separate it from the "Laurentian," or where the dividing line is to be found. How does he know that it is not the same as the other "Laurentian" rocks? He has never made any examination to see whether it is or not, and in the above-quoted remark of his he virtually acknowledges that he knew nothing of the rocks that he mapped as "Laurentian" in the district since examined by Dr. Rominger.

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* Geol. of Wisc., III. 627.

† Ibid., III. 98, 108, 117.

We tried to find some point where we could trace rock continuously from well marked and mapped "Laurentian" into the "Huronian," but were unable, with the time and opportunity at our disposal, to do more in that direction than we have already pointed out. The evidence is strong, but not so conclusive as we could have wished; yet what would it have availed us if we had found such a locality? We should have been told: "Oh! that is Formation XX. that you found; we knew nothing about the region, so we mapped it as Laurentian." May we suggest that hereafter geological maps of Lake Superior be colored as "Huronian," and "Formation XX."? Let us substitute the last term for the "Laurentian" at once, and have done with it before Formation XXII. is born. At another locality, the granite that Mr. Brooks assigns to "Formation XX." Professor Irving places under the "Keweenawan."†

While at Lake Superior the followers of Dr. Hunt thus place a troublesome granite cutting the "Huronian" as the latest formation in it (except one), in Eastern Massachusetts a granite said to cut and to be intrusive in the Primordial slates, as well as in the "Huronian" so called, is for this reason placed by them at the base of the "Huronian." Furthermore, the diabases that are intrusive in all, even the youngest rocks known here, are for that reason considered to be the equivalents of the "Norian," and regarded as older than the "Huronian." Now, if the granites are intrusive in the Primordial or Braintree slates, as we know the felsites are intrusive in the granites, and as we know the diabases are in all, we naturally should, as we have done, regard these rocks as crystalline eruptive ones, owing their crystalline character to crystallization from the molten magma, and geologically younger than the Primordial, i. e. Palæozoic rocks. But we see now that we were mistaken. Why not go to the Cordilleras and say of the basalts, These are "Norian" or "Naugus Head"; of the rhyolites, These are "Huronian"; of the trachytes and nevadites, These are "Laurentian," or "Formation XX."; of the andesites, —— ? Why not station one's self by a volcanic crater, and determine, as the eruption takes place, whether Formation V., XV., or XX. is rushing by?

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* Geol. of Wisc., III. 529, 530.

† Ibid., III. 193-195.

It seems, then, that in different localities different methods of interpreting the same facts are resorted to, but for the same purpose and result, — the rocks come out "Huronian" every time. Taking into account the methods pursued; the hypothesis, yet unproved by any careful, accurate work, that lithological evidence is conclusive; the assumption that foliation, banding, etc. of necessity prove stratification; the practice of inserting faults in the formations wherever it becomes convenient to do so in order to carry out the theory; that Dr. Hunt, in order to sustain his views, has, in Eastern Massachusetts, directly stated that the granite cuts the felsite, when the reverse is exactly the case, dike after dike of the latter cutting the former, as pointed out by us before,* and since most conclusively shown by Mr. J. S. Diller; † that the Norian rocks are probably in all cases eruptive basaltic rocks (gabbros); that the Keweenawan system has no foundation except in erroneous observation, as it conformably overlies the Potsdam sandstone, as we shall show later; — taking these and other things into consideration, we feel that the very basis on which the Laurentian, Huronian, and other such geological epochs were established, is yet an open question for discussion. Even in Canada the evidence is very far from being clear that the relations of the Laurentian and Huronian are what they are supposed to be. The agreement of hundreds of geologists in every quarter of the world does not establish anything, if that agreement is based on the same theories and methods, unless the theories and methods are correct. The evidence is clear enough in New England and at Lake Superior that the theory is unproved, and the methods and observations incorrect or superficial. It seems to us that a striking commentary on the value of lithological characters is afforded in the Marquette district by the letters and the comments upon them given on pages 657 to 660, inclusive, of the third volume of the Geology of Wisconsin.

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* Bull. Mus. Comp. Zoöl., V. 282.

† Proc. Bost. Soc. Nat. Hist. XX., 354.

We frequently are informed that microscopic analysis will make up for all deficiencies in field work; that one can tell in this way whether a granite or any other rock is eruptive or metamorphic; that Formation XX. is to be distinguished in this way from the Laurentian granite, etc., etc.*

The study of rocks microscopically enables us to investigate their structure, constitution, and alterations, — the structure of their constituents and the various relations that these bear to one another, as well as the order of their formation. It gives us the internal history of a rock more or less complete, — a thing that no other known method will do. It enables us to tell the species, arrange, and generally to classify our rocks. With the exception of such as are greatly altered, it enables us to distinguish the fragmental from the non-fragmental forms. When we are familiar with the microscopic characters of unchanged sedimentary rocks and of unaltered volcanic ones, they having been known to be such from field evidence, we have a basis for recognizing rocks, concerning whose field relations we know nothing, as belonging to one or the other of these classes, the same as by the unaided eye we recognize a coarse granite or conglomerate. This of course only applies to rocks concerning whose nature and origin there is no dispute; or to those which under the microscope show such undoubted evidence of their origin that it cannot be rejected. If a rock is clearly seen under the microscope to be made up completely of fragments, no one would doubt that it was a fragmental rock, even if it looked to the unaided eye as though it were a non-fragmental one. In like manner, when a rock has the microscopic characters of an eruptive one, we feel that it is right to regard it as such, even if it was *supposed* (not proved) to be a sedimentary one by the collector in the field. Both of these are of frequent occurrence in the work of a lithologist. Take now the great intermediate class of rocks, those that are so altered that their original characters are greatly or entirely changed, and the case is different. We can only proceed in safety when we know their field relations, or those of rocks that are like them. In order to know the microscopic characters of a sedimentary granite (if such a rock exists), it is necessary to study one that is known beyond question to be sedimentary, and to compare it with the most highly altered eruptive ones known. By this method of proceeding, always taking as the basis rocks whose relations to their fellows were known, diagnostic points of great value would be found, and a more just idea of the relations of the fragmental and non-fragmental forms obtained. The field evidence would have to be the arbiter in all cases. If a rock is eruptive, or if it is sedimentary, it is so, whatever may be its microscopic characters. In this class of rocks lithology is at present weak, and assumptions take the place of facts.

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* Geol. of Wisc., II. 73; III. 194, 255.

Although in no case in this paper have we attempted to give any elaborate microscopic analyses, but only a few of the more general facts, we have shown plainly enough the fallacy of determining the geological relations of highly altered rocks by microscopic analysis alone. Any one who takes pains to read pages 533 to 599, inclusive, of the third volume of the Geology of Wisconsin, will doubtless be convinced that different observers, under the present method of microscopic analysis and classification, reach widely different results in the study even of the same specimens. He can further compare our description of the Picnic point rocks with that given on page 567, and also with Mr. Brooks's statement that granite dikes "have never been observed in the Marquette series" (*l. c.*, p. 452). It is of course worthy of remark, that of the lithologists who have microscopically studied the rocks of Lake Superior, Messrs. Pumpelly, Wright, Irving, Hawes, Rutley, Julien, Törnebohm, and Wichmann, not one, so far as we can learn, had at that time any especial personal acquaintance with the characters of modern unaltered eruptive rocks, except possibly the two last named. Yet it is essential that one should be thoroughly acquainted with the unaltered forms of rocks before attempting to solve the most difficult lithological problems on the globe, i. e. those relating to the altered forms. As descriptions of what these observers saw in the individual specimens examined by them, their work is undoubtedly of great value; but beyond that there is a great chance for differences of opinion concerning their conclusions, or the basis upon which these were established.

The sedimentary rocks of the Marquette district generally give evidence of being shore deposits, and although they may have been deeply buried under later formations, yet in themselves we consider that they give no evidence of it.

The general structure of the country would seem to be as follows. The schists, sandstones, etc., having been laid down in the usual way, were then disturbed by the eruption of the jasper and ore; this formed the knobs of jasper, the banding belonging to the fluidal structure, and not to sedimentation. Besides occurring in bosses, the jasper was spread out in sheets, and intruded through the rock in wedge-shaped masses, sheets, and dikes. Much of the original rock still remained horizontal, and new sedimentary deposits continued to be formed out of the jasper and the other rocks. Next came the eruption of "diorite," which completed most of the local folding and tilting of the strata. Finally, the granite eruption took place on both sides of the "Huronian," uplifting and contorting the strata near it, and perhaps laterally compressing the enclosed iron-bearing rocks. No basis exists so far, then, for the scheme of formations laid down by Mr. Brooks, as it was founded on the supposition that all the rocks were sedimentary. The other results of our work are: the showing more clearly the age, origin, and nature of the peridotite at Presque Isle, and the formation of serpentine from it *in situ;* the finding of ottrelite schist as a metamorphosed rock from the ordinary schist; the showing that tourmaline and olivine are more abundant here than heretofore known; the finding of granite and felsite within the Marquette district, etc., etc.

Concerning the serpentine (peridotite) of Presque Isle Mr. Brooks remarks, "It is probably Huronian, and presents some of the phenomena of an eruptive mass." * Later he says, "It is not certain that this is of Huronian age." †

Although in deference to the common custom we have employed the term *jasper* in writing of the silicious eruptive rocks associated with the ore, in reality it is not properly called so. It is often uncolored, and has then generally been designated by observers as a quartz schist, they believing it to be sedimentary. The rock further has been denominated felsite or petrosilex, but physical and chemical characters remove it from these old rhyolitic rocks. It is more acidic than the rhyolites, the silica being above eighty per cent. We also found other eruptive rocks of like acidic character, and, so far as our observations have now gone, it seems probable that rocks of this class are much more abundant than we should at first suppose. They would naturally be taken at first sight for quartz schists, quartzites, and other sedimentary rocks, and no further investigations be made to ascertain their relations to the associated rocks. We would propose, therefore, that all the acidic eruptive rocks, whose chemical and physical constitution carries them above the rhyolites, should be designated as *Jaspilites* from ἴασπις and λίθος in accordance with a suggestion of Professor Whitney.

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* Geol. of Wisc., III. 532.

† Ibid., 659.

Finally, so far as our work has gone, it shows that Messrs. Foster and Whitney were right in their observations and conclusions, so far as it relates to the geological structure of the country, or to the origin of the rocks and ores, except the peridotite. To them and to them alone belongs the credit of having done their work accurately, and as thoroughly as the circumstances would allow, while the more recent observers and writers, Kimball, Credner, Rivot, Hunt, Dana, Brooks, Lesley, Winchell, Newberry, Wright, and others, have held and pushed theories in direct opposition to the facts, until a geologist who took a different view was regarded either with pity or derision. As regards the general geology of the country, we feel that Messrs. Foster and Whitney's writings remain to-day the best and most accurate exponents. Considering the difficulty of exploring the country thirty years ago compared with the present, it is surprising how much they saw, how accurate their observations were, and how little has been added to our knowledge since; also how our knowledge and science have again retrograded, until geologists have gone back to the views of Messrs. Houghton, Hubbard, and Locke.

The Copper District.

The earliest writer to advance any especial views regarding the copper and its origin, so far as we are aware, was Henry R. Schoolcraft.* He considers it probable that the masses of copper about the Ontonagon River were thrown out of volcanoes by volcanic action. The mountains are said to be of granite (Porcupine Mountains) so far as observed, and the sandstone to have been upheaved into a nearly vertical position at their base by the elevation of the granite. He considers that native copper will never be found in sufficient abundance to pay for mining, but that probably "valuable mines of the sulphuret, the carbonate, and other profitable ores of copper," will be discovered.†

In 1823, in describing a supposed vein of malachite on Keweenaw Point, he concludes "that the entire peninsula consists of a spine of

* Am. Jour. Sci., 1821, (1,) III. 201–216. Quart. Jour. Sci. and Arts, London, 1822, XII. 422, 423.

† See also Senate Papers, 2d Sess., 17th Aug., 1822, Doc. 5.

granite, with sandstones, amygdaloid, and secondary trap, deposited around its base." *

Dr. John J. Bigsby regarded the Lake Superior sandstone as being most probably of the age of the Old Red.† Commander H. W. Bayfield, in his paper entitled "Outlines of the Geology of Lake Superior," ‡ regards the hills of Keweenaw Point as formed of syenitic granite, of the same character as that at Granite Point, and opposes the idea that the first-mentioned point is an amygdaloid district. He regards the trap and granite as the prior formed rocks, and that the sandstone is composed of their *dêbris.* This sandstone, which he takes to be Old Red sandstone, is said to have been tilted by a secondary upheaving, or subsidence of the granite.

In Dr. Douglas Houghton's report on the copper of Lake Superior to the Secretary of War,§ we find the following statement: "After having duly considered the facts which are here presented, I would not hesitate to offer, as an opinion, that the trap-rock formation was the original source of the masses of copper which have been observed in the country bordering on Lake Superior; and that at the present day, examinations for the ores of copper could not be made in that country with hopes of success, except in the trap-rock itself; which rock is not certainly known to exist upon any place upon Lake Superior, other than Keweena Point." The chief ore of copper that he had observed was the malaconite, although a small amount of native copper had been seen in place.

Dr. Douglas Houghton states, in his first Report on the Geology of Michigan,‖ that the red sandstone "in the Trap regions of Lake Superior, as in the vicinity of the Porcupine Mountains, ... is seen dipping irregularly at a high angle from the elevated district of country, and is there of a deep reddish-brown color." He evidently at that time regarded the sandstone as belonging to one formation, from the St. Mary's River to the Porcupine Mountains.

Dr. Houghton in his Fourth Annual Report on the Geology of Michigan,¶ divides the sandstones of Keweenaw Point as follows, going from below upwards: "conglomerate rock," "mixed conglomerate and sand rock," and "red sandstone and shales." He regards the first as a "trap-tuff," and as made up of "rounded masses of greenstone and amygdaloidal trap, of which the former make up by far the larger proportion, and scarcely a pebble of any other rock than trap, enters into its composition." The second is composed of the same materials as the first, and is conformable with it. The only difference is that part of it is made up of sand composed of finely comminuted greenstone. The last, or "the red sandstone and shales," he considers to differ widely from the preceding rocks, and to be made up of detritus of the granitic and metamorphic rocks, containing, however, some sand that appears to be comminuted trap. This red sandstone extended, according to Houghton, as far east as Grand Island, where it was unconformably overlaid by the "Gray Sand Rock" (e. g. the material of the Pictured Rocks), which rested upon the uplifted edges of the former. It will thus be seen that he had changed his views since his first report.

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* Am. Jour. Sci., 1824, (1,) VII. 43-49.

† Quart. Jour. Sci., 1824, XVIII. 1-34, 228-269; Am. Jour. Sci., 1824, (1,) VIII. 60-88.

‡ Trans. of the Lit. and Hist. Soc. of Quebec, 1829, I. 1-43.

§ Nov. 14, 1831. Discovery of the Source of the Mississippi, Henry R. Schoolcraft, New York, 1834, pp. 287-292.

‖ Lanman's Hist. of Mich., p. 353.

¶ Joint Documents, Mich., 1841, pp. 472-607.

All these rocks were said to be traversed by dikes injected parallel to the bedding, varying in width from fifty to four or five hundred feet. He considered that the sedimentary rocks were all deposited prior to the injection of the traps, which rocks he finds very abundant in the conglomerates, and comparatively rare in the red sandstones. These dikes pass from a compact greenstone on the southeast side to an amygdaloid on the northwest. He considers that they were "in an intense state of ignition while in contact with the sedimentary rocks, as is clearly shown by the very great changes that have taken place in the rocks last alluded to. In fact, I am disposed to refer the origin of much of the amygdaloid rock to the fusion of the lower portions of the sedimentary rocks referred to, for the reason, that as we pass south from this junction, the amygdaloid rocks wholly disappear, their place being supplied by greenstone; and again so intimately are they blended, that it is frequently impossible to determine where the amygdaloid ceases and the upper sedimentary rocks commence. Fragments of the sedimentary rocks, the characters of which can be clearly recognized, are not of rare occurrence, imbedded in the amygdaloid rock, a circumstance which although by no means conclusive, should not be overlooked in considering this subject. I would not wish to convey the idea that the amygdaloid rocks have their origin exclusively from the altered sedimentary rocks, but simply that the change in the structure of the trap, from greenstone to amygdaloid, may and no doubt does depend upon the proximity of the sedimentary rocks to the trap, while the latter was in a state of ignition." (*l. c.*, p. 490.) He states that the sandstones have evidently been deposited in shoal water, on account of the abundant ripple-marks occurring in them.

Three species of fucoids, tolerably well defined, were said to have been found in the red sandstone. The veins are considered to be of a date posterior to the uplifting of the beds, and cut across all three of the sedimentary rocks and the traps. They are taken as true veins, and their mineral contents are said to change in the same vein as the rock changes. The gangue is said to be principally quartz with occasional calcite, and the ore to be most abundant at or near the junction of the trap and conglomerate. He regards this district as being in its general characters and in its veins like Cornwall. Conglomerates were noticed with a cement of copper, but only in the immediate proximity to considerable veins. He conceived the veins "to be veins of sublimation, or in other words to be simply filled from below by the metal in a vaporous state, and that all the compounds had their origin from copper in a native form." * In 1843, he considered that the sandstone east of Keweenaw Bay was older than the Trenton, while the western sandstones and conglomerates were formed during the period in which the trap was upheaved, and were probably contemporaneous with the New Red Sandstone.†

It will be seen here that Dr. Houghton had entirely changed his views regarding the relations of the sandstone. In 1841, the sandstone of Keweenaw Point was said to be older than the St. Mary's sandstone; in 1843, to be younger.

Later, Dr. Houghton "said he could not speak definitely as to the contemporaneousness" of this sandstone with that of Connecticut and New Jersey, "but he was sure of the *similarity* of their structure." ‡ Prof. B. Silliman, Jr. at the same time stated that although he had found the copper and silver from this region "fused into perfect union at their two surfaces," they were not alloyed.§

Prof. John Locke, in an article in 1844,‖ entitled "Observations made in the Years 1838, '39, '40, '41, '42, and '43 to determine the Magnetical Dip and the Intensity of Magnetical Force, in several Parts of the

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* Am. Jour. Sci., 1841, (1,) XLI. 183–186; 1844, XLVII. 106. Trans. of the Assoc. of Am. Geol. and Nat., 1840–1842, pp. 35–38.

† Am. Jour. Sci., 1843, (1,) XLV. 160.

‡ Am. Jour. Sci., 1843, (1,) XLV. 332; 1844, XLVII. 107, 132.

§ Am. Jour. Sci., 1843, (1,) XLV. 332.

‖ Trans. Am. Phil. Soc., Phila., IX. 283–315, Apr. 19, 1844.

United States," presents the metamorphic theory of the origin of the rocks of Keweenaw Point as follows: "The rocks of Copper Harbour, and indeed of the whole Kewenon peninsula, are decidedly metamorphic, showing every degree of change produced by igneous agency, from unchanged sandstone to compact greenstone. The stratification is, mostly, more or less evident, presenting in the various superimposed layers, an inexplicable variety, some layers bearing evidence of semi-fusion and a correspondent degree of induration and endurance, while others seem scarcely to have been altered, still remaining soft and yielding readily to atmospheric agency, and especially to the assaults of the waves from the lake. Whether these differences have been produced by an unequal distribution of the heat, or by an original difference in the layers of the strata, some being of a nature more susceptible of change by heat, I was unable to determine. . . . . Copper Harbour itself seems to have been formed by the removal of a softer stratum of metamorphic sand rock, while Porter's Island is a part of the barrier formed by the outcropping of a harder layer." (*l. c.*, pp. 311, 312.)

In 1845,* Lieut. D. Ruggles published a communication in which he advanced the view that the trap was projected in dikes through the New Red Sandstone, and that the veins were formed and filled "by volcanic or igneous action, under the pressure of incumbent waters." If we can judge from his statements about the copper and his description of the filling of the veins in the "Lead Region" of Illinois, Wisconsin, and Iowa, he believed that these veins were filled by the projection of metallic copper, enveloped in a dense atmosphere of oxygen "from the fountain of igneous action, through fissures in the rock strata, resulting from concurrent disturbing causes." When the vein was "under the pressure of an immense mass of water," the oxygen entered into combination with the copper to form the black oxide of copper, but when only under atmospheric pressure the oxygen escaped by sublimation, leaving the copper to its own resources.

Dr. Chas. T. Jackson, writing in 1845,† regarded the sandstones as probably Permian or New Red, but attributed to Dr. Houghton the belief that the formation is Old Red, and also held that the trappean rocks were injected dikes. The veins were taken as veins of igneous injection, although doubt is expressed, and he says: "When these veins occur near the trap dykes, analcime and Prehnite also abound, and were formed, without doubt, through the igneous agency of the trap on the contents of the vein and the ingredients of the wall rock." We may infer from this, that he regarded the fissures to be of anterior formation to the traps. He states that "the trap rocks of Lake Superior pass through the red sandstone and conglomerate rocks, and are interfused with them, producing at or near their junction a very porous amygdaloid, which is always found at the lower side of the dyke where it is next to the sandstone." He also remarks that he finds the copper and silver "united together side by side by fusion without any alloying of the silver"; "the two metals are completely soldered together at their points of contact." This paper was also presented to the Association of American Geologists and Naturalists, at their sixth meeting, April 1845, published in their Proceedings (pp. 53-60), and discussed by Prof. C. U. Shepard (pp. 60, 61). He considered that the copper was derived from the sandstones by the action of the trap dikes upon them. The copper was originally in the primitive rocks, "whose lateral slopes were occupied with cupreous strata derived from the degradation of the surrounding primitive; and that whenever the trap had slid out beneath these deposits, or in other ways come in contact with them, they would, as elsewhere, bring to the surface rich masses of copper; but he was inclined to the opinion that they would not give rise to deep and permanent mines." He considered that the sandstones belonged to the New Red. In an earlier portion of the Proceedings (pp. 30, 31), Dr. Jackson remarked that "at the junction of the great dykes with the sandstones of Nova Scotia, Maine, and on Lake Superior, a more violent ebullition took place than that which accompanied the eruption of the trap ranges in Connecticut, for the sandstone and trap are blown into a perfect scoria at the former localities; amygdaloid resembling the most porous lavas, and immense quantities of trap tuff containing lumps of metallic copper, evince the powerful action of trap on the sandstones of Nova Scotia, and on Kewenaw Point, Lake Superior. . . . . On Kewenaw Point we have an intimate mixture of copper and trap rock in the amygdaloid, and I at first supposed if the amygdaloid resulted from the interfusion of sandstone and trap, that the copper might have been reduced from copper ores pre-existent in the sandstones; but the absence of such ores in the sandstone in contact with or near the trap appears to discountenance the idea, and I am more disposed, since I have explored that region, to coincide with the opinion of Dr. Houghton in the belief that the copper of that region is a part of the primary copper of the globe brought up by the viscid trap." At a meeting of the Boston Society of Natural History,* November 6, 1844, he remarked: "There can be no doubt, however, that the metals found in the Lake Superior amygdaloidal trap, have been fused at as high a temperature as was required to liquify the rocks in which they are found, for they bear evident marks of entire fusion, and are as vesicular as the common lavas of Vesuvius, Etna, and Peak of Teneriffe."[*] In one of the later papers[†] he states: "It is obvious, both from the crystalline forms and the mode of occurrence of this copper, that it was deposited from a state of igneous fluidity; and, from the circumstance that the walls of the vein are encrusted with Laumonite, it would appear that the spar vein itself is of igneous origin. Many other instances of a similar kind indicate that the calcareous spar veins, which traverse the conglomerate and sandstone rocks, are true veins of igneous origin."

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* Am. Jour. Sci., (1,) XLIX. 62-72.

† Ibid., pp. 81-93.

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* Proceedings, I. 203.

Mr. Bela Hubbard[‡] regarded the sandstones on both sides of Keweenaw Point as Potsdam in age, and held that the traps were eruptive in it. He regarded, however, the conglomerate and the "mixed conglomerate and sand rock" lying to the northwest of the Point as of later origin than the trap and composed of its *débris*. Concerning the "mixed conglomerate and sandrock" he states: "As the finer strata of this rock have been mistaken by some for the red sandrock, hereafter described, it is important to observe that a very marked difference exists between the two rocks; for, while the latter is made up of materials derived from the several rock formations of the country, and into which quartzose grains enter most largely, the former is wholly derived from the trap rocks." The "red sandrock" is said to be in nearly horizontal strata, but having on the coast a slight dip inland, which becomes "more apparent as it approaches the basin of Portage Lake. In its approach to the trap, however, it is found more or less tilted from its original horizontal position, and is also very much altered by its contact with that igneous rock. The evidences both of the deposition of this extensive formation, in calm and shallow waters, and of the subsequent changes induced in it by the trap rocks, when in a fused or heated state, are very apparent."

Prof. H. D. Rogers[§] stated that "at the Eagle River mine, and elsewhere, the metalliferous rock is not, as sometimes supposed, a real trap rock, but a mixture of trappean matter, and that of the red sandstone formation, more or less baked and modified by intense igneous action. These semi-fused materials, in crystallizing, have very frequently resulted in the following curious arrangement: the crystalline metallic copper occupies the centre of globular and variously formed concretions; calcareous spar usually, but not always, invests the copper; and very generally the exterior of the kernel is pure crystalline chlorite. . . . These nodular lumps are dispersed through a base which exhibits a sort of pasty mixture of softened red shale and true trappean matter; and many of them are so surrounded as to indicate them to be true segregations from this semi-igneous, semi-aqueous compound." He regarded the sandstone as equivalent to the New Red sandstone of the Atlantic States, and making the same formation throughout the peninsula of Upper Michigan. In a report on the sale of mineral lands by Mr. Relfe we find the following statement: "In the conglomerate rocks which overlay the trap, are to be found all the varieties of copper ore of the richest qualities, offering to the smelter a greater yield than has ever been obtained from the copper ores of England or other countries that have contributed so largely of this important article." *

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[*] See also Proceedings of same Society, II. 110-114, Mar. 4, 1846. Am. Jour. Sci., (2,) II. 118, 119.

[†] Proc. Bost. Soc. Nat. Hist., 1846, II. 112.

[‡] Mineral Region of Lake Superior, by J. Houghton, Jr. and T. W. Bristol. See also Senate Documents, 1849-50, 31st Cong., 1st Sess., III. 802-842, and 1845-46, 29th Cong., 1st Sess., VII., No. 357, pp. 2-29.

[§] Proc. Bost. Soc. Nat. Hist., April 1, 1846, II. 124, 125.

Sir Wm. Logan in the Report of Progress† regarded the copper-bearing traps of Lake Superior as of a higher antiquity than the Potsdam Sandstone, and attributes the same view to Dr. Houghton in 1841. Logan's statement seems to be erroneous regarding Dr. Houghton's views in this respect. He considered the traps older than rocks which Logan regards as Potsdam sandstone, but of whose age he expressed no opinion in his Report for 1841, to which Logan refers. In 1843, as we have seen before, Dr. Houghton not only took the copper-bearing rocks to be of the age of the New Red sandstone, but also considered Logan's Potsdam sandstone as belonging to some formation older than the Trenton. In this way he had reversed his view of the order of succession in 1843, which Logan attributed to him as late as 1847. (*l. c.*, p. 34.)‡

Mr. Bela Hubbard in his report for 1846 § states concerning the trap of the Porcupine ranges that, "while we desire to avoid any theoretical conclusions as to the mode of their formation, we cannot but observe that the character of the entire trap formation is rather that of a succession of overflows, than of simultaneous uplift in mass; in other words, it may be considered as made up of *beds* of the different kinds superimposed upon each other." He also regards the "*epidote veins*" as in the main contemporaneous beds whose mineral contents were deposited with the bed.

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* Reports of Committees, 29th Cong., 1st Sess., Vol. III., Doc. 591, pp. 2, 3, 1845-46.

† Geol. of Canada, 1846-47.

‡ 1849 and 1851, Reports of Progress. North Shore of Lake Huron, p. 20; Brit. Assoc., pp. 59-62, 1851.

§ Senate Documents, 1849-50, III. 371-935, p. 887.

Dr. D. D. Owen, in his Report of a Geological Reconnoissance of the Chippewa Land District of Wisconsin, etc.,* of the date of April 23d, 1848, regarded the sandstone of Lake Superior as younger than the Carboniferous age, basing his conclusions, as Dr. C. T. Jackson had done, on lithological and mineralogical characters only. (*l. c.*, pp. 57, 58.) In his final report (Oct. 30th, 1851, pp. 187–193), this view was abandoned, and the sandstone regarded as Potsdam.

Dr. C. T. Jackson † remarked in 1848 that the sandstone agreed in its characters with those of the oldest of the sandstone formations. On Jan. 2d, 1850, (*l. c.*, p. 228,) he stated that he wished to correct the record, as the preceding view of the age of the sandstone should be accredited to his assistants, Messrs. Foster and Hill, and not to himself.

Mr. James T. Hodge ‡ seems to regard the veins as filled by igneous injection and sublimation. The silver was injected after the copper had cooled and occupied the spaces left by the contraction of the latter on cooling.

Dr. Charles T. Jackson in his report (pp. 392, 398, 399, 471–473),§ transmitted November 10th, 1849, stated that the amygdaloid was formed by "the interfusion of the red sandstone and trap," and the trap rocks are distinctly stated to have burst through and between the strata of the pre-existing sandstone. He calls attention to the mooted question whether the trap rocks originated from the molten interior of the earth, or were derived from the re-fusion of the lower stratified rocks (p. 397). The sandstone and conglomerate are said to have been derived from granite, gneiss, or mica slate and porphyry. The porphyry is thought to have resulted "from the semifusion of the finer materials of the sandstone. It is evident at once, from inspection of the pebbles of the conglomerate, that they have been ground into their present shape by long attrition under water, or upon some ancient shore. . . . . They originated from some nether rock, or were transported to their present location by drift agencies." Dr. Jackson will then stand next in order of time to Rev. J. G. Cumming in suggesting the idea of drift agencies in the earlier geological periods.* May we suggest that these conglomerates are the lateral moraines of the ancient glaciers which scooped out the basin of Lake Superior, and that the coldness of the waters at the time of the melting of these glaciers prevented the existence of life then. In this way we account for the Lake basin, the conglomerates, and the absence of fossils, three difficult problems. As we now know the geological structure of the country to be different from that supposed by Dr. Jackson, there exists an excellent field here for speculation concerning the number of glacial periods during the time of the deposition of the rocks of Keweenaw Point, the connection of glaciers with volcanic action and the eccentricity of the earth's orbit. It is very probable that the ice by its weight carried the sedimentary strata downwards, the same pressure aiding in their igneo-aqueous fusion (solution), while the thickness of the ice mass would cause the geothermal *couches* to rise, thus enabling us to account for the lavas. This leads us to the consideration of the effect that glaciers may have in forming lake bottoms by their pressure bending the underlying strata, the displaced material being erupted along the sides of the depression. We can thus account for the proximity of volcanoes to large bodies of water, and explain the cause of the highest mountains being adjacent to the deepest oceans, their successive elevations corresponding to the different glacial epochs. If the Atlantic is to be filled with a solid mass of ice to account for the loess of the Rhine, and the Southern oceans to be filled in like manner to explain the geographical distribution of the New Zealand fauna, why cannot Lake Superior also be filled, when it will cost so little and explain so much?

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* Senate Documents, 1st Sess., 30th Cong., 1847–48, VII., Doc. 57, 134 pp.

† Proc. Bost. Soc. Nat. Hist., III. 76, 77, Nov. 1st, 1848.

‡ Proc. Am. Assoc. Adv. Sci., Aug. 20th, 1849, II. 301–308.

§ Senate Documents, 1849–50, III. 371–935. See also Proc. Am. Ass. Adv. Sci., II., 1849, Aug. 20, pp. 283–301; Bull. Geol. Soc. France, (2,) Vol. VII., 1849–50, pp. 667–673, and Am. Jour. Sci., (2,) Vol. X., 1850, pp. 65–77.

Dr. Jackson further considers the sandstone as belonging to the New Red, stating that it has been absolutely proved not to be Potsdam. He seems to have receded from his former views regarding the filling of the fissures by vein material and not to have adopted any others in their places. He would, however, consider that the copper and silver "were produced by igneous agency. . . . . The copper and silver occur on

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* History of the Isle of Man, 1848, p. 89. See also F. B. Hough, Proc. Am. Assoc. Adv. Sci., 1851, VI. 262–264; and the Quart. Jour. Geol. Soc., VI. 96, 97, 1850, R. Godwin Austin; XI. 185–205, 1855, A. C. Ramsay.

Lake Superior mineral lands in the trap rocks only, and the valuable veins are limited to a narrow belt of the amygdaloidal variety of that rock." (*l. c.*, p. 471.) Mr. J. W. Foster (May 26, 1849, *l. c.*, pp. 773–785) regarded the sandstone "as resting at the base of all the fossiliferous rocks."

In Foster and Whitney's Report to the Land-Office (*l. c.*, p. 607), it is stated that "what is generally known as the trap range, consists of a belt of igneous rocks, composed for the most part of hornblende and felspar, which in places have broken through the sandstones, tilting them up at high angles; but oftener are found in alternating beds, having the same dip as the detrital rocks. The associated sandstone and conglomerate belong to the silurian system, and rest at the base of all fossiliferous rocks." Concerning the copper it is stated: "Some of these accumulations of copper are mere beds, the result of segregation, while others are contained in fissures, formed subsequent to the containing rock, and associated with a veinstone entirely dissimilar." (*l. c.*, p. 608.)

The final report of Messrs. Foster and Whitney on the Copper Lands was presented April 15, 1850.* Regarding the trap range of Keweenaw Point, it is stated that "this range does not appear to have been the result of one, but of successive overflows; for we not only find the igneous materials arranged in parallel bands, and exhibiting great diversity in external characters, but we also find numerous intercalations of conglomerate of inconsiderable thickness, but extending for miles in a linear direction — these mixed products being associated in regular beds, having a common bearing and inclination, so that the inexperienced observer is inclined to refer the whole to a common origin. This deception is still further increased by observing lines of pseudo stratification in the trap conforming to those of the associated sedimentary rocks." (*l. c.*, p. 61.)

The southern trap range of the Point is said to consist of "a vast crystalline mass, forming an anticlinal axis, flanked on the north by the bedded trap and conglomerate, and on the south by conglomerate and sandstone." (*l. c.*, p. 64.) Towards Portage Lake none of this trap was protruded, but it was thought that the same fissure extended along this line from the "head of Keweenaw Point to the western limits of the district." (*l. c.*, p. 68.) Regarding the relations of the sandstone to the trap on Keweenaw Point and Isle Royale, they say: "As a general observation, the *upper* portions of these sandstone belts are much more changed by heat than the lower." (*l. c.*, p. 63.) "The *upper* portions of the sheets of trap are highly vesicular, resembling pumice.

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* Executive Documents, 1st Sess., 31st Cong., 1849–50, IX., Doc. 69, 224 pp.

Fragments of amygdaloid, sometimes rounded, at others angular, are found enclosed in the pumice-like trap, as though they had become detached and afterwards reunited to the mass, while in a molten state. Numerous short and irregular fissures, extending to no great depth, are observed on the upper surface of the trap, in which sandstone has been deposited. . . . . Between the *sandstone above* and the *trap below*, it is extremely difficult to determine where the one begins, and the other ends. Fragments of amygdaloid, angular or partly rounded, are included in the sandstone — more numerous near the base than at the top of the deposits. Where the sandstone is imposed *on* the trap, there is little evidence of its having been metamorphosed; but, on the other hand, where the trap rests *on* the sandstone, the line of junction is clear and well defined. The trap is less vesicular; and the upper portion of the sandstone belt, for the distance of three or four feet, is converted into a ribbon jasper, having a compact texture. These phenomena have been observed at numerous places both on Isle Royale and Keweenaw Point. The beds of sandstone are not shattered, nor does the igneous rock penetrate in the form of dikes or ramifying veins. All the phenomena indicate that the igneous rocks were not protruded in the form of dikes between the strata, but that they flowed like lava sheets over the pre-existing surface; and that the sand was deposited in the fissures and depressions of the igneous belt, in some cases while the mass was in an incandescent state." (*l. c.*, p. 87.) The conglomerate is regarded as a volcanic tuff, and the sandstone as Potsdam in age. The conglomerate of Keweenaw Point and Isle Royale "consists of rounded pebbles of trap, almost invariably of the variety known as amygdaloid, derived probably from the contemporaneous lavas, and rounded fragments of a jaspery rock which may have been a metamorphosed sandstone, the whole cemented by a dark-red iron sand. This cement may be regarded as a mixture of volcanic ash and arenaceous particles, the latter having been derived from the sandstone then in the progress of accumulation. . . . . The trappean pebbles often attain a magnitude of eighteen inches in diameter. Their surfaces do not present that smooth, polished appearance which results from the attrition of water. . . . . The conglomerate appears to have been formed too rapidly to suppose that the masses were detached and rounded by the action of waves and currents, and deposited with silt and sand on the floor of the ancient ocean; for, while the contemporaneous sandstone remote from the line of volcanic foci does not exceed three hundred or four hundred feet in thickness, the united thickness of the conglomerate bands in the vicinity of the trappean range on Keweenaw Point exceeds five thousand feet. As we recede for a few miles from the line of the volcanic fissure, these amygdaloid pebbles disappear, and are replaced by arenaceous and argillaceous particles." (*l. c.*, pp. 99, 100.) "Although the conglomerate attains a thickness of five thousand feet, yet it by no means follows that the ancient sea in which it was deposited extended to that depth. Ripple-marks and clay-cracks have been observed in the upper portions of this group; the one indicates comparatively shoal water, and the other the ebbing and flowing of a tide, or a change in the level of the water. The inference, therefore, is, that during the deposition of the conglomerate, the bed of the sea was subject to repeated elevations and depressions, caused by volcanic action, and that its water obeyed the same tidal laws which govern the existing oceans. These conglomerates, then, may be regarded as local deposites formed along the courses of the volcanic fissures by the joint agency of fire and water. When the former causes operated with intensity, the materials consisted of spherical masses of lava and scoriæ. When they acted feebly, or were quiescent, the materials became argillaceous or arenaceous." (*l. c.*, p. 109.) "We have seen that, during the deposition of the sandstone, numerous sheets of trap were ejected, and flowed like lava-streams; and that the igneous and aqueous products were so intermingled as to present the appearance of having been derived from a common origin; and that subsequently the unbedded trap broke through these parallel fissures, lifting up the sandstones, conglomerates, and bedded traps, and causing the whole mass to dip at high angles." (*l. c.*, p. 110.) The sandstone on both sides of Keweenaw Point, and the trap, were regarded as making one geological formation.

While the sandstone is stated to dip near the southern range of trap above Bête Grise Bay 78° southeast (*l. c.*, p. 112), farther up Keweenaw Bay the prevailing dip was said to be about 5° to the northwest (*l. c.*, p. 116). The veins were regarded as probably filled by materials "once held in aqueous solution and precipitated by electro-chemical agency," while the theories of sublimation and injection were controverted (*l. c.*, pp. 174, 175). The veins were fully described so far as then known, as well as the order of deposition of the minerals and associated copper, etc., etc.*

Prof. Louis Agassiz, in discussing the "Geological Relations of the various Copper Deposits of Lake Superior,"* wrote concerning the copper ores: "They seem to me clearly to indicate that the native copper is all plutonic; that its larger masses were thrown up in a melted state; and that from the main fissure through which they have found their way, they spread in smaller injections to considerable distances; but upon the larger masses in the central focus, the surrounding rocks could have little influence. New chemical combinations could hardly be formed between so compact masses, presenting, in comparison with their bulk, a small surface for contact with other mineral substances capable of being chemically combined with the copper. But where, at a distance, the mass was diffused in smaller proportions into innumerable minute fissures, and thus presented a comparatively large surface of contact with the surrounding rocks, there the most diversified combinations could be formed, and thus the various ores appear in this characteristic distribution. The relations which these ores bear to the rocks in which they are contained, sustain fully this view, and even the circumstance that the black oxide is found in the vicinity of the main masses, when the sulphurets and carbonates occur at greater distances from them, would show that this ore is the result of the oxidation of some portion of the large metallic masses exposed more directly to the influence of oxygen in the process of cooling. Indeed, the phenomena respecting the distribution of the copper about Lake Superior, in all their natural relations, answer so fully to this view, that the whole process might easily be reproduced artificially on a small scale; and it appears strange to me that so many doubts can still be expressed respecting the origin of the copper about Lake Superior, and that this great feature of the distribution of its various ores should have been so totally overlooked."

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* See also Bull. Geol. Soc. France, (2,) VII. 1850-51, pp. 89-100; Proc. Am. Assoc. Adv. Sci., 1851, V. 22-38, 136-151; and Am. Jour. Sci., (2,) 1851, XII. 222-239.

Prof. J. D. Dana remarked: "The copper occurs in trap or sandstone, near the junction of these two rocks, and has probably been produced through the reduction of copper ores by the heat of the trap when first thrown up."† This view is retained in his later editions of the same work.‡

Dr. C. T. Jackson later advocated his former view that the sandstone of Keweenaw Point was of the same age as the New Red sandstone of Europe, but in addition he claimed that this sandstone (New Red) was a member of the Upper Silurian.* Later, Mr. Jules Marcou advocated the view that this sandstone was of the age of the New Red, and opposed the ideas of Messrs. Foster and Whitney.† At the meeting of the British Association for the Advancement of Science, July, 1851, Sir W. E. Logan ‡ advanced the idea that the sandstone and its associated traps were older than the Potsdam, and of Cambrian age. This view was based on the idea that the azoic rocks north of Lake Huron were the same as the traps of Keweenaw Point.§ Dr. D. D. Owen, as mentioned before, in his "Geological Survey of Wisconsin, Iowa, and Minnesota" (pp. 187–196) regarded the sandstone as of the same age as the Potsdam of Wisconsin, but Col. Chas. Whittlesey (Ibid., pp. 459 – 461) was inclined to think it was older. Dr. J. J. Bigsby || believed the sandstone to be Cambrian (or Silurian). Later, Dr. C. T. Jackson advocated the igneous origin of the calcite veins in this region.¶ Mr. Jules Marcou, in his "Geological Map of the United States, with Text," held that the sandstone was of the age of the New Red, and apparently regards the trap as having been injected in the form of dikes. The copper veins were also thought to be dikes, with the copper of like igneous origin. This work gave rise to a long controversy, in which the age of the sandstone was quite thoroughly discussed; but in only a few cases shall we refer to the various articles elicited by it. Those interested in the literature of the Marcou - Anon.- Agassiz - Barrande - Blake - Dana - Hall - Hunt - Logan - Murchison-Whitney controversy will find the principal articles, that have any bearing on the geology of Lake Superior, given under the names of the different authors in the list of articles at the end of this paper.

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* Lake Superior: its Physical Character, Vegetation, and Animals, (Boston, March, 1850,) pp. 427, 428.

† System of Mineralogy, 3d ed., May, 1850, p. 508.

‡ 4th ed., 1854, Part II. p. 17; 5th ed., 1868, p. 15.

The same views regarding this district that were given in Messrs. Foster and Whitney's Report on the Copper Lands were again presented in brief in Professor Whitney's "Metallic Wealth of the United States." ** Dec. 5th, 1855, Dr. Jackson explained the deposition of the copper in the veins "as the result of the chemical action of protoxide of iron in the trap-rock, which decomposed the vapor of chloride of copper, as it rushed from the interior of the earth through the crevices; if, as is probable, these wonderful native copper lodes, are

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* Proc. Bost. Soc. Nat. Hist., Oct. 2 and 16, 1850, III. 335 – 339. See also Bull. Soc. Geol. France, (2,) 1849 – 50, VII. 209, Elie de Beaumont.

† Bull. Soc. Geol. France, 1850 – 51, (2,) VIII. 101 – 105.

‡ Trans. of the Sections, pp. 59 – 62.

§ See Am. Jour. Sci., (2,) 1857, XXIII. 305 – 314.

|| Edinburgh New Phil. Jour., 1852, LIII. 55 – 62.

¶ Proc. Bost. Soc. Nat. Hist., 1853, IV. 308, 309.

** Philadelphia, 1854, pp. 247 – 305. Am. Jour. Sci., (2,) 1857, XXIII. 305 – 314.

the products of sublimation and of galvanic segregation of the metal from vapor." He defined the ash bed as a "comparatively soft scoria, or rotten amygdaloid, formed by the mixture of molten trap-rock and fine sandstone, which have been, as it were, melted together into a very spongy kind of scoria, the aqueous vapor having rendered it remarkably vesicular."* He regarded the trap as having been "poured out, at different times, through a fissure, and spread over the materials of the sandstone and conglomerate at the bottom of the sea, thus producing alternating beds of these rocks," while in July, 1856, he seems to have regarded the trap as forming dikes in the sandstone, and combining with its ingredients to form the zeolites.† Prof. L. E. Rivot‡ regarded the traps as interstratified sedimentary beds metamorphosed *in situ*. The sandstone formed the upper portion of, and was conformable with, the copper series; all to the Sault St. Marie making one geological horizon, including the granites and iron-bearing rocks. All were taken to be of the Potsdam age. The veins were considered to have been produced by elevation and fracture since the deposition of the entire series, and the copper deposited in the wet way.

In 1856 a "Report on the Exploration of Lakes Superior and Huron," was presented to the Legislative Assembly of Canada by Count de Rottermund. It probably proved satisfactory, as we do not learn that the Assembly asked for any further information from him. In the narrative portion we are informed: "I procured a boat with four hands and proceeded to Portlock Harbour. . . . I met Mr. Salter with whom I returned to the Bruce Mines. There we parted our provisions and separated." (*l. c.*, p. 1.)

He attempts a classification of the formations visited, and states that "this classification demands great attention, and very minute discrimination, to avoid the solecism of giving names according to individual fancy, not used in the scientific world. Such are the names applied to formations in Canada of Huronian, Sillery, Laurentine, Richelieu, peculiar to the localities which they indicate, substituted for Jurassic, Carboniferous, Cambrian, Devonian, etc., which are so well classified, defined, and admitted throughout the scientific world." (*l. c.*, pp. 4, 5.)

His theory of the origin of the copper is too lengthy for insertion; it must be read to be appreciated. The result is summed up as follows: "On Lake Superior the copper, in its native state is due to the deposit of certain species of organic matters which have a tendency to increase the electro-chemical action, and which decomposed the sulphurets, oxides, etc., which the abundant deposit of matter containing traces of talc serpentine and chlorites, has brought together or concentrated in a certain limited space. For nearly all the rocks contain in the crystalline cleavage, and also in the veins these matters which appear sometimes to be a sort of cementation, if, indeed, it be not the state of combination of detritus, of disintegration of primitive rocks which have arrived at the state of sandstone and greywacke." (*l. c.*, p. 13.)

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* Proc. Bost. Soc. Nat. Hist., 1855, V. 279-281; 1859, VII. 31.

† Ibid., VI. 23, 24.

‡ Annales des Mines, (5,) 1855, VII. 173-328; 1856, X. 364-474.

This report is not without interest to the archæologist as the following proves: "I have in my possession locks of hair enveloped in copper, which the natives carried about them as marks of their bravery. Whenever they killed their enemy they used to cut off a lock of hair and carry it about them as a species of decoration. In places where there is no copper they cut off with the hair a small portion of the skin, which is called the scalp." (*l. c.*, p. 16.)

The student of Indian customs can, of course, now greatly aid the miner in his prospecting, if he will carefully map the districts inhabited by the non-scalping, copper-bearing Indians, for hereafter it will be of no avail to look for copper outside of their habitat.

Alb. Müller, in 1856, published a paper relating to the copper of this district.* His facts were taken mostly from the report of Foster and Whitney, and it is unnecessary to repeat them here. He regarded the copper as being deposited in the wet way, by the aid of galvanism, and reduced by organic matter and the oxide of iron. The copper, it is supposed, might have existed in the trap and its minerals, in minute amounts, until brought to the points where it is now found. The student interested in the origin and deposition of the copper will do well to read the writings of Foster and Whitney, Whitney, Müller, Bauerman, and, lastly, those of Marvine and Pumpelly.

Principal J. W. Dawson remarks † concerning the deposition of the native copper: "The whole of the appearances indicate that the deposition of copper belongs to the period of aqueous infiltration, by which the veins and vesicles were filled after the consolidation of the trap; and the copper, like the calc spar and zeolites, occurs both in true veins and in the cavities of beds of vesicular trap and tufa. Its deposition must, therefore, be explained, not by igneous causes, but by electro-chemical agencies, decomposing some soluble salt, most probably the sulphate, of copper. Such changes may have been aided by the remaining heat of portions of the volcanic masses, by the presence in them of large quantities of iron in low states of oxidation, and by the further oxidation of that metal evidenced in the red jasper and red laumonite of the veins, and the red conglomerate and sandstone associated with the trap. . . . . The main fact in relation to the origin of the metallic copper, is that it is a product, not of the fusion of the trap, but of subsequent processes, by which the fissures of that rock were filled by materials regarded as of aqueous origin." (*l. c.*, pp. 8, 9.)

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* Verhandlungen der Naturforschenden Gesellschaft in Basel, 1854–57, pp. 411–438.

† Feb. 10, 1857. Canadian Nat. and Geol., II. 1–12.

In 1857, Dr. J. D. Dana* stated that the veins occur "mostly in the trap rock which intersects a red sandstone, probably identical in age with the red sandstone of Connecticut and New Jersey." April 6, 1859, Dr. Jackson inclined to the view that the zeolites had been formed "under the heat of the trap rocks, and the influence of heated saline waters." † Prof. James Hall, in his Palæontology of New York,‡ says: "In the region of Lake Superior, the sandstone, of the age of the Potsdam sandstone, has accumulated to a degree unparalleled in any other known locality of that rock. In this region there are not only massive accumulations of trappean matter, but outflows which have spread over the strata during their deposition; the beds of stratified amygdaloid trap alternating with the shale and sandstone, often equalling or exceeding the sedimentary matter."

In 1861, Dr. T. Sterry Hunt, following Logan, referred the sandstone with its accompanying trap to the Quebec group.§ Prior to this,‖ Prof. W. B. Rogers supported the view that this sandstone was of Potsdam age, and was opposed in this by Dr. Jackson.

In his Manual of Geology,¶ Dr. Dana refers the sandstone partly to the Potsdam and partly to the Calciferous epoch. In the edition of 1874, it is regarded as Calciferous. Dr. Dana further remarks concerning the copper, that "the native copper of the Lake Superior region is intimately connected in origin with the history of the trap and sandstone. The copper occurs in irregular veins in both of these rocks near their junction; and whenever the trap was thrown out as a melted rock, the copper probably came up, having apparently been derived from copper-ores in some inferior Azoic rocks through which the liquid trap passed on its way upward. The extent to which the rock and its cavities are penetrated and filled with copper shows that the metal must have been introduced by some process before the rock had cooled."*

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* Man. of Min., 2d ed., p. 305.

† Proc. Bost. Soc. Nat. Hist., 1859, VII. 45-47.

‡ Vol. III. p. 79, 1859.

§ Am. Jour. Sci., (2,) 1861, XXXI. 216-220, 392-414; 1862, XXXIII. 320-327. Canadian Nat. and Geol., 1861, VI. 81-105, 199-207.

‖ Proc. Bost. Soc. Nat. Hist., Nov. 17, 1860, VII. 394-399.

¶ 1862, pp. 172-174.

In the Geology of Canada, 1863, the copper-bearing rocks are considered, by Sir W. E. Logan, to be of the Calciferous and Potsdam formations, but overlaid by the Eastern sandstone, which was regarded as Chazy (pp. 67 – 86). Dr. Hunt seems to regard the "ash-bed" of Copper Falls as a conglomerate, and further says, regarding the Portage Lake deposits: "Certain of the sedimentary beds thus impregnated with native copper, are often designated as volcanic tufa or volcanic ash. From whatever source derived, however, the amygdaloidal rocks were deposited from water; and the copper which is disseminated in them, as well as in the sandstones and conglomerates, was separated by chemical processes from aqueous solutions, either contemporaneously or by subsequent infiltration. There appears to be no doubt that the traps which are interstratified with the sandstones and amygdaloids of this region, are eruptive rocks; and the sedimentary material of which the amygdaloids and tufas are composed may perhaps have been, to a greater or less extent, erupted in the form of volcanic mud, as many geologists suppose. This origin of the sediment has probably, however, no connection with the source of the copper." (pp. 698, 699.) He takes the entire formation, as before, to belong to the Quebec group.

In 1866, Mr. Thomas Macfarlane regarded the rocks at Portage Lake as melaphyrs.† In 1868 (*l. c.*, p. 256), he appears to regard the sandstone as being of the Permian age, basing his conclusions upon the lithological characters of the melaphyrs, while those who had regarded it as Triassic have based their views upon the lithological characters of the sandstone. One method is about as valuable as the other, a flow of basalt lava or a deposit of sand not being apt to be dated *per se.* Colonel Whittlesey, in describing the continuation of this formation in Wisconsin, makes the copper-bearing trap a formation below, but conformable with the Potsdam sandstone.‡ Mr. H. Bauerman§ suggests, besides the hypothesis of Müller, the following to account for the occurrence of the copper: "The presence of copper in the sandstones suggests another origin — namely, that it may have originally been deposited with the quartz-ore sediment as a finely divided sulphide from sea-water under the influence of organic matter, and by subsequent oxidation and solution have been removed and collected in the rocks below. . . . The size of the accumulated masses of metal appears to be mainly dependent upon the size of the cavities in which they are deposited, whether in the amygdaloids or in the main fissures; and their absence in the compact traps is probably only due to the non-occurrence of such cavities. In almost all cases the introduction of the metal has been preceded by the deposit of minerals produced from the decomposition of the rock, such as quartz, calcite, chlorite, and zeolite; and in the larger cavities it is often followed by transparent crystals of calcite, which are formed over branching masses of copper, or even show signs of simultaneous deposition, being filled with fire-spangles of metal arranged parallel to the diagonal striations or lines of growth on the rhombohedra. Similar alternations in the formation of zeolites, more particularly analcime, have been described by Whitney." He is inclined to regard the deposition of the copper in the amygdaloids as having taken place prior to the filling of the veins, the former serving as feeders to the latter. (*l. c.*, pp. 460, 461.)

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* Edition of 1862, p. 195; see also edition of 1874, p. 186.

† Geology of Canada, 1866, pp. 149 – 164. Canadian Nat. and Geol., (2,) III. 1 – 18.

‡ Proc. Am. Assoc. Adv. Sci., 1867, XVI. 97 – 107.

§ Quart. Jour. Geol. Soc., 1866, XII. 448 – 463.

In a paper read before the Boston Society of Natural History, June 5, 1867,* Mr. Alexander Agassiz remarks: "Foster and Whitney, in their Report of the Lake Superior mineral district, represent the sandstone on the south side of the trap range of Keweenaw Point as dipping south and resting conformably upon the beds of trap of the north side of the anticlinal axis of Keweenaw Point. This anticlinal axis formed by the Bohemian Mountain, as asserted by Foster and Whitney, is not found further south as far as I have had occasion to examine. In two of the ravines cut through the sandstone by creeks flowing in an easterly direction from the crest of the range towards Torch River, near the head of Torch Lake, we find good exposures of the sandstone resting unconformably upon the trap which has still the same northern dip as further west, of about 42°. The sandstone within a distance of one hundred feet from the trap, dipping north 42°, lies horizontally, or rather has at the outside an inclination of $1\frac{1}{2}$° or 2° south." At the falls of the Douglass Houghton Creek, he says: "The creek winds its way through a deep ravine cut out of the sandstone, and at the junction of the sandstone and trap, falls a depth of one hundred and seventy-two feet. The chloritic bed is well developed on the south side of the creek, while the north side is more greenstone, and all along the whole length of the ravine up to the falls, a distance of one and one-half miles, the horizontal beds of sandstone are readily traced, dipping slightly north near the falls, and being horizontal at the opening of the ravine into Torch River valley, plainly showing that they rest unconformably upon the trap range. On examining this sandstone more carefully, we find that the strata are made up of alternating layers of sandstone of reddish or yellowish grain, and of beds of loose sandstone containing boulders; some of the beds of boulders resembling what is common on sea-shores as a mixture of mud and shingle. On breaking open several of the small boulders taken *in situ* from the beds we find that they consist mostly of reddish trap, but frequently we come across perfectly well water-worn boulders of grayish trap containing amygdales, identical with the trap of the copper range a short distance west from these beds of sandstone, plainly showing that the sandstone was deposited upon the shores of the ridge of trap forming Keweenaw Point, and has not been uplifted by it as is stated by Foster and Whitney. The case is totally different with the sandstone north of the range that lies conformably upon the trap, but the sandstone of the southern side of the mineral range in the vicinity of Torch Lake is plainly of a different age, lying, as it does, unconformably upon the former."

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* Proceedings, XI. 244-247.

In some respects it would seem that Mr. Agassiz, in common with many geologists, had misunderstood the views of Messrs. Foster and Whitney. Their idea was that the traps and sandstone comprised the same formation. The present visible portion of the eastern sandstone had, like the western one, been laid down since the trappean overflows.

After the deposition of the entire series a fissure was formed running along the Point from its head to the western limits of the district. This was attended in the northeastern portion by the protrusion of trap forming the Bohemian Mountains, but towards Portage Lake the fissuring was accompanied only by the elevation of the sandstone and trap west of the line, while that east of it remained nearly horizontal. As no stratified rock can rest conformably on the intrusive mass which uplifts it, so the sandstone was not supposed to rest conformably on the Bohemian trap. They also did not in their final report regard the sandstone along this fissure at the Douglass Houghton fall as dipping southerly, although Mr. Foster had stated so in a previous report to Dr. Jackson.* That Messrs. Foster and Whitney had this idea was probably inferred from the fact that the printer placed the eastern side of their section on the left hand, as was also done with that of the Copper Falls mine.* Their idea then would be perfectly consonant with the presence of trappean pebbles in the eastern sandstone as well as in the western, only they would have been deposited prior to the faulting, instead of after it, as Mr. Agassiz's view would demand.

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* Senate Doc., 1849 – 50, III. 783.

Mr. Robert Bell† regards the Upper Copper-bearing rocks as being of Permian or Triassic age. This conclusion was based on the lithological characters, and was objected to by Sir Wm. Logan in the same report (pp. 472 – 475).

Prof. R. Pumpelly in 1871 published a paper on "The Paragenesis and Derivation of Copper and its Associates on Lake Superior,"‡ a subject which had been treated of before by Messrs. Whitney, Müller, and Bauerman. He remarks: "The eastern limit of the 'range' is formed by a strongly marked and generally vertical plane of demarkation between the highly inclined cupriferous series of rocks and the sandstones which slope gently to the S. E. This sudden break is considered, with probably the best of reasons, by Foster and Whitney, and afterwards by Rivot, to be a longitudinal fracture accompanied by a dislocation of at least several thousand feet. Foster and Whitney looked upon the sandstone as the equivalent of the Potsdam, while the Geologists of the Canadian Survey refer it to the Chazy, and both authorities agree in considering it to be younger than the cupriferous rock, and of the same age as the sandstone beds, which are conformably superimposed over the trappean series on the west side of Keweenaw Point."

Prof. Pumpelly, it would seem, believed that the copper was deposited in the places in which it is now found by being precipitated from solution through the agency of protoxide of iron. He further considered that the copper was derived by concentration from the sedimentary members of the series. He remarks that "it is still an open question whether the trap which formed the parent rock of the melaphyr was an eruptive or a purely metamorphic rock. If it was eruptive, it was spread over the bottom of the sea in beds of great regularity, and with intervals which were occupied by the deposition of the beds of conglomerate and sandstones." (*l. c.*, p. 352.) The general tenor of this and his other papers shows that at this time, and for some years afterward, he leaned strongly towards the theory of the sedimentary origin of the entire trappean series. At this time he also regarded the traps, with all the sandstone as far east as at least the Pictured Rocks, as belonging to the Quebec group. It will be seen that he afterwards abandoned these views.

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* Copper Lands, pp. 63, 68.

† Geology of Canada, 1866 – 69, p. 321.

‡ Am. Jour. Sci., (3,) II. 188 – 198, 243 – 258, 347 – 355.

Later, Prof. Pumpelly in conjunction with Major T. B. Brooks published a paper entitled, "On the Age of the Copper-bearing Rocks of Lake Superior." * They state that their observations "demonstrate a wide difference in age between the Cupriferous series of sandstones, conglomerates, and melaphyres on the one hand, and the Lower Silurian sandstone, with which they have generally been considered as nearly identical in age, on the other." At the western edge of the eastern sandstone on Keweenaw Point "its nearly horozontal strata abut against the steep face of a wall formed by the upturned edge of beds of the Cupriferous series of melaphyre and conglomerate, which dip away from the sandstone at angles of 40° – 60°, according to geographical position. This sharply defined and often nearly vertical plane of contact, having been seen by the earlier geologists at several points along a distance of many miles, and having been found to be often occupied by a thick bed of chloritic fluccan, which was looked upon as the product of faulting motion, was considered as a dislocation. This idea seemed to gain corroboration in the fact that, on the western side of Keweenaw Point, sandstones bearing considerable resemblance to those of the eastern horizontal beds occur, apparently conformably overlying the Cupriferous series. Both sandstones came to be considered as identical in age, and as forming the upper member of the group. There were many circumstances which made it difficult for us to accept this conclusion. One obstacle lay in the enormous amount of dislocation required; for instance, at Portage Lake, where the strata of the Cupriferous series, with an actual thickness of several miles, dip away from the supposed *longitudinal* fault at an angle of about 60°." The Cupriferous series is regarded by them as conformable to the Huronian, while the line of fault is taken to be an old shore cliff, with the sandstone deposited against its base. They also state that it would be difficult to account for the absence of this series in localities eighteen miles from where they were found miles in thickness, unless they represented a sinking area along whose shores the Silurian sandstone was deposited. They also claim that this series was worn through near Lake Gogebic, and the Silurian sandstone deposited in the trough. It is to be noticed that according to them the Cupriferous series are four miles distant from the locality in which the Silurian

* Am. Jour. Sci., (3,) III. 428 – 432, 1872.

sandstone is said to have been seen. Their geological reasoning could only hold good in a region where uncontorted sedimentary rocks *alone* occur; therefore we are justified in believing that at this time both Pumpelly and Brooks regarded the copper-bearing traps as metamorphosed sedimentary rocks. We are not aware that the latter has ever changed his views.

In 1873, Dr. T. Sterry Hunt* used the term *Keweenian group* in speaking of the copper-bearing rocks, and suggests that perhaps the copper may have been derived from the oxidation of copper ores in the Huronian schists, while the dissolved metal accumulated in the basins at their base, — a view almost identical with that announced by Shepard twenty-eight years before. "We may here remark that the late researches of Messrs. Brooks and Pumpelly seem to establish that the great copper-bearing series of Keweenaw occupies a place between the Huronian schists and the nearly horizontal red and white sandstone of the region which is itself below the Trenton limestone. In all this they have confirmed the previous conclusions of Houghton, Whitney, Hall, and Logan." It may be remarked here, also, that if Prof. Whitney's writings have taught anything, it is that the sandstone from Sault St. Marie to the further side of Keweenaw Point, including the copper-bearing rocks, are one and the same formation; therefore Dr. Hunt's statement is incorrect in this particular at least. In proof of this, one can read his own statement of Prof. Whitney's ideas on page 79 of the "Azoic Rocks." † As we have shown before, Houghton regarded the copper-bearing rocks as eruptive in, and therefore younger than, the sandstone of Keweenaw Point, which in 1843 he took as belonging to the "New Red." This is the last published statement that we can find of Houghton's on this point.

Mr. Brooks, in his Report on the Iron Districts of Lake Superior, ‡ regards it as proved that the copper-bearing rocks are conformable with the Huronian; the proof was obtained, not from contacts, but from their common dip and strike. He also states: "Against and over the copper series on the north, abut the horizontally bedded lower Silurian sandstones. . . . . As the *non-conformability* of the copper-bearing rocks and sandstones is doubted by some geologists, it should perhaps be stated that the actual contact was not seen. But the sandstones were observed lying horizontal, and affording not the slightest evidence of disturbance, within a few miles of highly-tilted copper rocks, which gave every evidence of having been elevated before the deposition of the sandstones. So far as my observation has extended, this rule is general; that is, no Lake Superior sandstone, which is unmistakably lower Silurian, has ever been found in any position other than nearly horizontal";—Will Mr. Brooks visit Presque Isle?—"and no rock which was unmistakably of the Copper series has been seen which was not considerably tilted. The fact that certain sandstones belonging to the copper series are very similar, if not lithologically identical with some of the lower Silurian sandstones, has helped to complicate this question. An interesting locality for study in this connection is the west fork of the Ontonagon River, just south of the Forrest Copper Mine. I am not sure but that it affords an exception to the rule above stated, as at that point sandstones, *apparently* Silurian, dip south at an angle of 45°."

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* Trans. Am. Inst. Min. Eng., I. 331 – 342.

† Sec. Geol. Survey of Penn. E, Azoic Rocks, Part I.

‡ Geol. of Mich., I. 184, 185.

In Prof. Pumpelly's Report of the Survey of the Copper District,* we find but little written by him of geological interest excepting that which had been published elsewhere, and referred to in the preceding pages.† The sandstone beds on the eastern side of Keweenaw Point are said to slope gently to the southeast (*l. c.*, p. 1). The chief portion of the geological work, and about all of any value, seems to have been done by Mr. A. R. Marvine, who, judging from his work, appears to have possessed the power of observing well and accurately in the field. Only certain portions of his work can be pointed out here: "The conglomerate beds of Keweenaw Point have been generally considered as mere local deposits, rapidly fading out in either direction. The table would seem to show, on the contrary, that for conglomerates they are unusually persistent, and that while a bed may thin out and lose its character as a conglomerate, it may still exist even as a mere seam. . . . . We gather from those facts that when the beds composing the trappean range were being originally formed, the agencies, whatever they were, which formed what are now the melaphyrs, ceased to act not only over limited but over extended areas, in one instance at least over fifty (50) miles, and for periods of time long enough to allow of the accumulation of beds of conglomerate from a few to over 75 feet — in one instance over half a mile — in thickness." (*l. c.*, pp. 60, 61.)

Mr. Marvine points out the fact that much of the amygdaloidal character of these rocks is owing to chemical action upon approximately homogeneous rock long after it was formed, and "the amygdules which mark this change were thus slowly developed, and are not the mere fillings of pre-existing cavities." Besides this pseudo-amygdaloidal structure true amygdaloidal structure was also pointed out. Concerning the sedimentary origin of these rocks he remarks: "But the strongest proof would seem to be in the structure of the so-called scoriaceous amygdaloids. In these, patches or balls of amygdaloidal material are associated, even surrounded by an imperfectly stratified material, which is undistinguishable from the true fine-grained sandstones. This association is such that it seems as if it could in no wise be accounted for by metamorphism acting on sedimentary beds, but only by supposing a peculiar mixture of the materials at the time of deposition, which mixture is not such as sediments assume. . . . The fact that in sandstones which are intercalated between two trap beds the upper parts, for several inches from the hanging wall, are often changed as if by heat, while at the bottom contact there is no such change, cannot be offered as an objection to the metamorphic theory, for it would be in just such regions that metamorphism would naturally occur. But the fact that sandstone material seems to have entered amygdules near the upper part of beds covered by sandstones; that it may fill a well-defined crack extending down into an underlying melaphyr, ... or that melaphyr may nearly surround pebbles apparently caught up from an underlying conglomerate . . . .; these facts, as does the peculiar structure of the scoriaceous amygdaloids above noticed, seem to point to a very different origin for the melaphyrs than a sedimentary one. . . . As a whole, then, the *structural* features of these beds remarkably resemble those of true lavas. They have been affected, however, and to a very great extent, by metamorphism, and this metamorphism has taken place in such a manner, has so heightened and carried on the original structure, as it were, that the ordinary proof of their igneous origin, such as contact changes in adjacent sandstones, presence of amygdules, etc., fail, and it seems natural to consider this metamorphism as a *vera causa* for the whole structure. Certain extraordinary features, however, as noticed above, seem wholly incompatible with this idea, and when considered as true igneous rocks in which great and peculiar metamorphism has taken place, all the phenomena presented seem to be satisfactorily and naturally accounted for. . . . These changes, however, have been both very many and very great; so great, in fact, that, as seen above, when once examined they seem almost sufficient to have developed all the peculiarities of the beds from sedimentary deposits. The practical importance of the recognition of this metamorphism and of a proper understanding of its methods and effects, will be apparent when it is recollected that to it is due all the economical value the beds possess. The beds as originally formed probably contained the elements of its minerals, together with its copper and silver, more or less disseminated through their mass, as much so remains till the present day, or else they were so contained — at least in part — in overlying rocks, and in this form they could have been of no economic value; nor could any process taking place at that time have concentrated the minerals in the manner in which they now occur." He opposes the theory that the copper was deposited in its present position by igneous action.

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* Geol. of Mich., Part II., 1873.

† Am. Jour. Sci., 1872, (3,) II. 188-198, 243-258, 347-355; III. 428-432.

The metamorphic action is thought to have resulted from the agency of percolating waters. "All the phenomena tend to prove that it is by means of some such chemical actions as these, continued through long periods of time, that the metamorphism of these beds has been effected. It is such metamorphism which has developed the amygdaloidal melaphyrs, formed segregations, modified and filled the veins and amygdules, placing in them their minerals in the present relative positions; and, in the general process, the copper, like the other ingredients, was selected from its disseminated and therefore useless condition, and concentrated in veins, amygdaloids, and conglomerates till it reached a percentage of richness that gives to the deposits an economical importance. This action has taken place certainly not at a high temperature, and possibly at a temperature no greater than that of the beds at present, while it may have been largely aided by that electric action which chemistry almost always induces, and which is known to be active at the present day. In fact the presence of the latter is proof that chemical action is even yet going on. . . . .

"Where observed, the hanging-walls of the sandstones were generally smooth and gently undulating, but occasionally quite uneven, while the upper two to twelve inches were somewhat changed, being harder or softer, or lighter or darker-colored than the mass of the bed. . . . . The foot-walls are sometimes smooth and undulating; the surface of the underlying bed, when not an amygdaloid, as was sometimes the case, seeming to have been worn smooth, as if by attrition; or else the sandstone seemed to fill inequalities in the underlying amygdaloid. The sandstones were not observed to be changed near the foot-wall. In one remarkable instance, a crack or fissure was observed extending down into a melaphyr, which was filled by the overlying sandstone. The conclusion is inevitable, that the melaphyr had formed, hardened, and cracked before the sandstone was deposited. . . . .

"The veins of the district were of course formed long after the consolidation of the beds, and probably when they were being lifted into their present position. They have subsequently been filled with the various minerals which now occupy them, wholly by infiltration and chemical, probably aided by attendant electric, action, and in a systematic and natural sequence." (*l. c.*, pp. 108 – 115.)

Regarding the junctions of the sandstone and amygdaloid in two localities he says: "*Junction*, very irregular. For two feet the underlying sandstone is changed and indurated, being, in places, hardly distinguishable from the overlying melaphyr, except for enclosed pebbles which are not changed. Some pebbles rest upon the hanging-wall, which are quite enclosed in the overlying amygdaloidal melaphyr. . . . . *Junction*, slightly undulating. No change or metamorphism in the adjacent beds. Extending from the junction down into the underlying melaphyr — about eight feet being exposed — is a fissure or crack with sharply defined edges and two abrupt bends, giving widths of two and four inches. This crack is filled with sandstone similar to that above, but somewhat finer and slightly decomposed or softened. There is an appearance of irregular, but rudely curved stratification, about parallel, as a whole, with the formation." (*l. c.*, pp. 118, 119.)

It is to be seen, then, that Mr. Marvine arrived at the same conclusions regarding the Copper-bearing rocks as did Messrs. Foster and Whitney, and supported these views by the same evidence that they had more fully and thoroughly given in their report.

In Part III.* we have the report of Dr. C. Rominger on the Palæozoic Rocks. Regarding the sandstone he says: "The lower Silurian age of the Lake Superior sandstone is unequivocally proved by its stratigraphical position. In its whole extent it is visibly overlaid by calcareous ledges, containing fossils peculiar to the Calciferous formation, or, in other cases, by the Trenton limestones. The recognition of a separate rock-series, identifiable with the Calciferous formation, at once nullifies the other mentioned opinions of Geologists, and leaves no choice but to see in the Lake Superior sandstone the equivalent of the Potsdam sandstone. . . . . The thickness of the Sandstone formation is difficult to ascertain. Its lower portions are so intimately connected with the sandstones and conglomerate beds of the copper-bearing Trappean series, that I could draw only an arbitrary division line between the two groups, which would swell the thickness of the sandstone group to many thousand feet, while east of the Copper range, the whole sand-

* Geol. of Mich., I. 1873.

stone series reposing on the Huronian and Granitic rocks does not exceed the thickness of 300 feet." (*l. c.*, pp. 80, 81.)

"The sandstones lining the eastern shore of Keewenaw Point extend approximating to the centre of the Peninsula, retaining their horizontal position, and also their lithological characters to such a degree that the different strata can be parallelized without difficulty with those of the more eastern localities. Near the centre the horizontal sandstone ledges are found at once abutting against the uplifted edges of a different rock-series — the *Copper-bearing rocks* — which form the most elevated central crest of the Peninsula." (*l. c.*, p. 95.) "The discordance of the strata on the east side of the axis of elevation, and their conformability on the sloping west side, finds its explanation in the hypothesis of a gradual submarine upheaval of the trap range, in its subsequent rupture, and the final emergence of the western margin from the water, while the eastern portion of the fissured earth's crust remains submerged." (*l. c.*, p. 98.)

In 1874, Prof. Roland Irving discusses the question of the age of the copper-bearing rocks of Wisconsin, which were regarded as identical with those of Keweenaw Point. He advocates the same views as those held by Pumpelly and Brooks, and bases his conclusions on similar grounds. The Laurentian, Huronian, Copper-bearing rocks, and Lower Silurian sandstones were never seen in direct contact with one another with one exception. That exception is the junction of a trap supposed to belong to the Copper-bearing series with the Potsdam sandstone. The sandstone, he states, is for three hundred feet from the trap "broken in every conceivable manner, the misplaced layers dipping in all directions, and in its immediate vicinity making a sort of brecciated mass of fragments of trap and sandstone. . . . . These trappean beds carry here *no intercalated beds of sandstone and conglomerate*." He objects to the most probable explanation in this case, the protrusion of this trap through the sandstone, as the trap seems to be unlike the Copper-bearing rocks, except in the fact that it is an old basalt; but thinks some deep-seated force shoved the old formation, on whose flanks the sandstone was deposited, upwards, and so produced this dislocation.*

Concerning the relation of the western sandstones to the eastern and to the trap rocks in the Ontonagon district, Dr. Rominger says: "The age of these beds is intermediate between the trap and the horizontal sandstone deposits; but between all three of the indicated groups so great lithological affinities exist, that it is most natural to consider them as the consecutive products of one and the same epoch, in the commencement of which the just-formed strata were displaced by volcanic action, which subsided toward the end and left the last deposits undisturbed." *

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* Am. Jour. Sci., (3,) VIII. 46-56; Trans. Wisc. Acad. Sci., 1873-74, II. 107-119.

In 1878, Prof. Pumpelly published a paper entitled the "Metasomatic Development of the Copper-bearing Rocks of Lake Superior." † This is devoted principally to a description of the microscopic characters of these rocks and their alterations, and, although we differ in nomenclature, we regard it as one of the very best papers published upon microscopical lithology. His geological ideas remain the same, however, as he states that the greater age of the Keweenaw series over the Potsdam sandstone is proved by abundant evidence of non-conformability. He regards them "more nearly conformable to the underlying highly tilted Huronian schists. They are thus the product of the earliest eruption of basaltic rocks to which a proximately definite age can be assigned. They were preceded by very extensive eruptions of acid rocks, especially porphyries. These basaltic rocks have been subjected to a wide-reaching alteration, which has produced marked changes in the internal condition of the beds, and has filled the fissures with a rich variety of minerals, whose constituents were derived from the products of this alteration." (*l. c.*, pp. 253, 254.) These old basaltic rocks were considered to be melaphyrs and diabases.

It is to be seen that he now adopts the views of the origin of the traps held by Messrs. Foster and Whitney, and later by his assistant, Marvine. The reasons for this radical change of base are not stated: we have simply the assertion that the traps are basaltic overflows, made as though no one had ever held a different opinion.

Later, Dr. T. Sterry Hunt says that it seems probable from our present state of knowledge that the traps are of volcanic origin. He regards them as unconformable with the Huronian, as he takes the Copper-bearing rocks as the equivalent of his Taconian. This, of course, requires the intercalation of his Montalban between them and the Huronian. ‡

Dr. J. D. Dana in his Manual of Mineralogy and Lithology, § says concerning the occurrence of the native copper with disseminated silver: "This mixture of copper and silver cannot be imitated by art, as the two metals form an alloy when melted together. It is probable that the separation in the rocks is due to the cooling from fusion being so extremely gradual as to allow the two metals to solidify separately, at their respective temperatures of solidification — the trap being an igneous rock, and ages often elapsing, as is well known, during the cooling of a bed of lava, covered from the air." We may remark here that Hunt's edition of Ure's Dictionary, 1878, states that the West Canada copper mines are the most important in America. Such carelessness of statement should hardly be allowed in a work of its purported character.

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* Geological Survey of Michigan, 1873–1876, III. 154.

† Proc. Am. Academy, XIII. 253–309.

‡ Sec. Geol. Survey Penn. E, Azoic Rocks, Part I. p. 236.

§ New York, 1878, p. 131.

Mr. A. R. C. Selwyn, in the Canadian Naturalist,* opposes the use of the numerous names based upon purely theoretical lithology; i. e. Norian, Montalban, Taconian, Keweenian, etc., in the crystalline rocks. He includes the Copper-bearing rocks in the Huronian. His views, however, were objected to by Mr. Thomas Macfarlane.† Mr. Selwyn's paper was again published in the Report of Progress of the Canada Geological Survey for 1877 – 78 (A, 15 pp.).

In the third edition of Prof. J. D. Dana's Manual of Geology (p. 778) we are given his views concerning the deposition of the copper at Lake Superior as follows: "When eruptions of melted rock have taken place, they have often brought not merely the heat of great depths to the surface, but also, various mineral materials encountered on the way up, and especially some of the metals or their ores.

"The fissures were in general deeper than those that gave origin to veins of segregation, for the latter did not reach to where melted rock could fill them, and hence had to be filled by what they could get through the slower process. They consequently must have descended to regions of very high temperature. As in a volcanic conduit, whatever at these depths, in the heated subterranean region adjoining the opened passage-way, was ready to pass into a state either of vapor or liquidity, would have been forced, by the pressure to which it was subjected at those depths, to escape, if possible, by the way made for the liquid rock, and would have ascended either along side of the latter, or within its mass; and at the same time, a portion would have been liable to be forced into the wall rock of the fissure wherever it was not of too close a texture to receive it. The mineral material that could take advantage of such an opportunity, or be aided in it by the heat of the ascending melted rock, would be that, as just implied, which was most easily fused or vaporized; and this includes certain metals and their ores, especially those of copper, silver, and antimonial, arsenical, and sulphurous ores of lead, or of lead with silver or copper. The fusing points of pure copper and silver are below 2,500° F., that of copper being, according to Riemsdyk's experiments, at the Utrecht mint, in 1869, 2426° F. and that of silver, 1904° F.; and hence these might have passed into the melted rock in the liquid state; but whether this was the fact, or whether they were in vapor, or in some vaporizable or soluble compound, is not definitely known.

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* 1879, (2,) IX. 17 – 32.

† Remarks on Canadian Stratigraphy, Can. Nat. and Geol., (2,) IX. 91 – 102.

"The above is a general explanation of the initial movement in the making of copper mines like those of Lake Superior, in which the metal is in the native state, and the silver mines of Nevada, Mexico, Bolivia, Chili, Transylvania, and of many other regions, which afford various ores of silver with often some native silver. The igneous rock of the Lake Superior region is largely doloryte, and copper is in fissures and cavities in the igneous rock, and in the sandstone of the walls."

In the third volume of the Geology of Wisconsin the copper-bearing rocks are regarded as older than the sandstone, but younger than the Huronian. The traps, with their associated sandstones and conglomerates, are called the *Keweenawan series*, while the supposed unconformable sandstone is regarded as Potsdam. The evidence advanced is good, so far as it goes, but it proves nothing until it shall be shown that the old basalts studied in each particular case are not dikes, but overflows identical in age with those on Keweenaw Point, and that they are not earlier or later eruptions. In this respect the strongest evidence advanced by the Wisconsin geologists is fatally defective. Their methods of observation fail in giving the proof necessary to establish their conclusions, which may or may not be correct, so far as their work goes.

Historical Summary.

The theories advanced concerning the Copper district are so various and conflicting, in many cases even in the writings of the same author, that we cannot hope to do justice to them in a brief summary.

The principal points to which we have directed attention thus far are: 1st, the origin of the traps and their interbedded sandstones and conglomerates; 2d, the relation that the traps bear to the eastern and western sandstones; 3d, the age of the eastern sandstone; 4th, the origin of the veins and the copper deposits.

Concerning the origin of the traps, it has been seen that they were said to be in dikes, generally intruded through the series of sandstones and conglomerates, by Houghton, Jackson, Shepard, Hubbard, and Marcou. They were thought to be in lava overflows by Hubbard, Foster and Whitney, Jackson, Bigsby, Hall, Hunt, Pumpelly, and Irving. They were regarded as metamorphosed sedimentary rocks by Locke, Rivot, Pumpelly, and Brooks, while the amygdaloidal portion was said to have been formed from fused sandstone by Houghton and Jackson, and from sedimentary material, possibly volcanic mud, by Hunt. The latter author at first taught that the traps were eruptive, but separated the amygdaloids from them.

The traps were supposed to be of a prior age to the sandstones by Bayfield (who thus long antedated the views of Pumpelly and Brooks), Logan, Whittlesey (who regarded them as conformable with the sandstones), Alexander Agassiz, Pumpelly, Brooks, Hunt, Rominger, Irving, and Selwyn. They were said to be younger than the sandstone by Houghton, Jackson, and Marcou. They were taken to be of the same geological age as the sandstones by Hubbard, Foster and Whitney, Jackson, Bigsby, Rivot, Logan, Hall, Dana, Pumpelly, Hunt, and Rominger.

The traps were assigned to a geological age distinct from the eastern sandstone, and given the name *Keweenawan* by the Wisconsin geologists, *Keweenawian* by Brooks, and *Keweenian* by Hunt. Logan and Selwyn assigned them to the Huronian, the latter doing so principally on account of the erroneous observations of Pumpelly and Brooks.

The eastern sandstone of Keweenaw Point was regarded as Old Red by Bayfield and Bigsby; as New Red, by Houghton, Ruggles, Jackson, H. D. Rogers, Shepard, Owen, Marcou, and Dana; as Potsdam, by Hubbard, Foster and Whitney, Owen, Logan, Hall, W. B. Rogers, Rivot, Rominger, and Irving; as partly Potsdam and partly Calciferous, by Logan and Dana; as Calciferous, by Dana; as Chazy, by Logan; as Quebec, by Logan, Hunt, and Pumpelly; as Permian, by Macfarlane; and as Permian or Triassic, by Bell. The sandstone was also thought to be older than the Potsdam by Logan and Whittlesey.

Dr. Houghton at first regarded the sandstone and trap from the Sault St. Marie to the Porcupine Mountains as the same formation; later, he thought that the sandstone west of Grand Island was unconformably overlaid by that east of that island; still later, the sandstones east of Keweenaw Bay were said to be older than the Trenton, while the Copper-bearing rocks were thought to be New Red.

The veins were thought to have been formed anterior to the traps by Jackson, and at the time of their eruption by Dana and Marcou, but by the majority of the observers posterior to the consolidation of the entire series of rocks. They were believed to have been filled by injection by Houghton, Ruggles, Jackson, Agassiz, and Marcou; by injection and sublimation, by Hodge; by sublimation, by Houghton and Jackson; and in the wet way, by Foster and Whitney, Rottermund, Müller, Bauerman, Dawson, Pumpelly, Marvine, Hunt, and others. Houghton regarded the district as identical with Cornwall. The copper was supposed to have been thrown from volcanoes by Schoolcraft, while H. D. Rogers and Dana teach that it was deposited during the cooling of the trap. Ruggles, Agassiz, and Marcou regard it as injected in dikes from the molten interior, while Bauerman and Pumpelly teach that it was originally deposited in the sandstone from the sea-water through the reducing agency of organic matter. This view seems to be shared by Hunt, who likewise, in common with Shepard, thought that copper was derived from the *débris* of ores in the older rocks, and deposited in the sandstones. Prof. Shepard thought that it was concentrated from the sandstones, and brought to the surface by the action of the traps. Whether Dr. Hunt teaches that the copper was derived directly from the sandstones and deposited in the veins, or was brought up by the extravasated traps, which, according to his theories, must have originally formed the lower portion of the Keweenawan series, and was thence concentrated in the veins, we cannot tell, for, as is frequently the case in his writings, his English admits of more than one construction. Müller, Bauerman, and Marvine think that the copper may have been an original constituent in the traps in a finely divided condition. Prof. Dana teaches that it was derived from ores in the older rocks by the action of the traps, and holds, with Houghton, Jackson, and Shepard, that it was brought up by the trap. Foster and Whitney, Dawson, Müller, Bauerman, Pumpelly, Marvine, and others, would refer the concentration to electro-chemical action. Benjamin Silliman, Jr., and Jackson said that the copper and silver, when found joined, had been fused together; while Hodge explained the phenomenon by supposing that the copper was injected first, and by its contraction left vacant spaces into which the silver was injected later. Such, in brief, are some of the various theories advanced.

The Traps.

In order to ascertain the origin of these rocks, we have to examine, first, their relation to one another, and, second, to the interlaminated sandstone and conglomerate.

The relations of these rocks can be well studied in an adit about one mile long, extending from the western sandstone through alternating beds of sandstone, conglomerate, and trap, to the ash-bed at the Copper Falls mine. We find here that the sandstone, when underlying the trap, has its upper portion adjacent to it baked and indurated; showing the usual characteristics of a ferruginous sandstone when subjected to a certain amount of heat. This indurated sandstone has frequently been subjected to secondary water action since it was buried under the trap, and hence has lost some of its hardness and other signs of baking. No fragments of the trap were found in the immediately underlying sandstone, but tongues of trap extend down into it in some places, and indurate it. The surface of the trap underlying the sandstone is water-worn, forming smooth, rounded knobs and irregularities, upon which the sandstone was deposited. The immediately overlying sandstone shows none of the baking and induration that the underlying one does. In no case, so far as we saw, was there any difficulty in separating the sandstones or conglomerates from the traps. The upper side of the sandstone was especially distinctly separated from the overlying trap, while on the under side, on account of the composition of the sandstone, the junction was not so obvious. While the trap always affected its underlying sandstone, and frequently included masses of it, in no case did it produce any effect on the overlying one. The sandstones or conglomerates at their base contain fragments and pebbles of the underlying trap; but this detritus diminishes as we recede from the trap, and is generally wanting after a thickness of two or three feet has been laid down. The trap is found to be cellular and amygdaloidal on its upper side, but on the lower to be compact and more coarsely crystalline. If the traps had been intrusive between the beds of sandstone, both the upper and underlying sandstone would be alike affected adjacent to the trap. If the trap was formed from the sandstone metamorphosed *in situ* there ought to be some gradual passage between the two, and the fragments of sandstone enclosed in the trap should more especially show such passage. On the contrary, nothing of the kind could be found, but the sandstone fragments were greatly indurated, and the traps adjacent to them filled with quartz (646, 647, 648). Specimens 469, 478, 479, 480, 482, and 483 from the Calumet and Hecla, and 621 from the Copper Falls mine, are examples of the contact of the sandstone with the underlying trap, and 477 and 478 from the Calumet and Hecla, and 577, 578, 579, 610, 611, 612, 613, and 620 from Copper Falls, show the contact with the overlying trap. The only explanation of these facts, which were first pointed out by Messrs. Foster and Whitney, and later by Mr. Marvine, is that given by them, that the traps are lava flows, and that they were successively laid down upon one another, or covered by sandstone and conglomerate. They are seen to have the same characters, except so far as they have undergone secondary changes, that modern basaltic lavas have. These old basalts have been denominated melaphyrs and diabases by Prof. Pumpelly, to whom lithologists are indebted for their knowledge of their microscopic characters. While we would use the terms that Prof. Pumpelly has, we object to the application he has made of them. Many of his diabases we should call melaphyrs, and many of his melaphyrs we should class as diabases. We of course differ in our definitions of these terms, for while he would regard melaphyr and diabase as distinct rock species, we hold that they are only altered forms of basalt. The greenstone ridge back of the Cliff and Phœnix mines we regard as an excellent example of diabase (791, 792), with which we class all the heavy-bedded crystalline traps of that region, while the thin-bedded scoriaceous or amygdaloidal highly altered traps we class as melaphyr, but in the majority of cases Prof. Pumpelly regards them as the reverse. The diabases are rarely if ever mined, the melaphyrs frequently.

In a recent paper "On the Carboniferous Volcanic Rocks of the Basin of the Firth of Forth — their Structure in the Field and under the Microscope,"* Prof. Geikie points out the difference microscopically between lava flows and intrusive masses, and evidently thinks that they can always be as readily separated in the cabinet, microscopically, as they can be in the field. While it is doubtless true that this separation can be made in the rocks studied by Prof. Geikie, his distinctions fail in the Lake Superior district. The difference in structure pointed out by him seems to be entirely owing to the rate of motion and pressure at the time of crystallization, and the rapidity with which the lava solidified. When lava flows in thin sheets, or, if we confine our examination to the upper portion of a thick sheet, we find characters that readily distinguish the sheets from the dikes; but when we come to study the middle and lower portions of the thick sheets, where there was little or no motion combined with the pressure of the overlying mass, the rock is undistinguishable from rock of the same composition in dikes; and the diagnostic characters given by Prof. Geikie would assign it to an intrusive rock, not to an overflow. In the before-mentioned Emerson adit at the Copper Falls mine, some melaphyrs were seen that were apparently in the form of dikes intruded since the lava flows (624, 626, 627, 628).

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* Trans. Royal Soc. of Edinburgh, XXIX. 437–518.

The form of lava locally known as "ash-bed" has attracted considerable attention. It has been described in various ways, generally being regarded as fused sand and trap. Latterly Prof. Pumpelly has described this as "volcanic scoriæ buried in the littoral sand."* At the present time the ash-bed can be best studied at the Copper Falls mine, where it is largely mined for the copper it contains. After a careful study of it, we conclude that the ash-bed is a very scoriaceous, and, comparatively speaking, somewhat thin lava flow. It does not possess the ordinary characters of the other flows of Keweenaw Point, but seems to be largely made up of clinkers and scoriaceous masses. It appears to have flowed in a more or less fragmental condition, forming a black, rough, loosely aggregated, scoriaceous, cinder and lava sheet, similar to those described by Prof. Whitney in his "Report on the Geology of California," † and by Prof. Palmieri in his "Account of the Eruption of Vesuvius of 1871 – 72." ‡

At the time of the flow, or since, the interstices were filled with detrital mud. The various parts of the flow seem to be connected in the main, and do not form to any great extent true pebbles.

That the rounded fragmentary portions derive their structure from the cooling of a fluid mass, and not by water action on the melaphyrs, is shown by their cellular structure in the interior, and solid crust on the exterior, the same as similar modern lavas have. Water-worn pebbles of melaphyr, as seen at some of the old burrows of the Hancock mine in a detrital deposit (832, 833), which to the casual observer resembles the ash-bed, have the cellular structure extending throughout the mass, and are destitute of any crust.

The same flow exists at the Petherick and Old Phœnix mines, while a similar formation is mined at the Atlantic. Besides the true ash-beds, there seem to be confounded with them certain sedimentary deposits composed of rounded water-worn pebbles of melaphyr held by littoral sand. These forms pass into a more siliceous conglomerate or sandstone, or not, according to the length of time that elapsed before the succeeding flow. They are abundant west of Houghton, and, so far as I could find, are the only formations existing at the Hancock mine that could have led Prof. Pumpelly to state that an ash-bed was worked there.* Specimen 814 is a good example of the end of a lava mass, which still retains its original ropy and fluidal surface structure. This came from the ash-bed at Copper Falls, and gives conclusive evidence that it had never been water-worn. Tongues of the ash-bed were seen extending down into its underlying trap, while the overlying trap sends tongues down into the ash-bed (Fig. 27).

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* Proc. Am. Acad., XIII. 283.

† 1865, Vol. I. p. 267.

‡ Annali del reale Osservatorio meteorologico Vesuviano, (Napoli, 1873,) p. 28. The same, translated by Robert Mallett, (London, 1873,) p. 103.

From their nature all the various lava flows are liable to be limited in any direction, either from their thinning out, the flow meeting obstructions, or from denudation since deposition, but before being buried under conglomerate or the succeeding flow. They were evidently poured out on a shore line, whose position probably varied relatively to the traps. The intervals between the different flows seem to be brief in some cases, while in others considerable time must have elapsed. Figure 28 shows the relation of the trap to the sandstone at one point in the Emerson adit at Copper Falls, exhibiting the irregular surface of the latter before the lava flow.

The Sandstones and Conglomerates.

As we followed the Hungarian River, a tributary of Torch Lake, upward, starting from the low sandy plains near the lake, the sandstone was first observed forming high bluffs on both sides of the river, and dipping N. 45° W. 10°. It occurs in coarse and fine layers often enclosing pebbles. As the river is ascended the layers of pebbles were seen to curve in various directions with an irregular dip, but which in general inclined to the northwest. Some of the pebbles appeared to be of quartzite similar to that at Carp River, Marquette (522). The Hungarian Falls are formed by the river being precipitated over several ledges of the sandstone and conglomerate. Several specimens were taken, showing the different varieties of pebbles composing the conglomerate (523, 524, 525, 526, 527, 528, 529, 530). No. 523 is an old trachyte composed of a reddish-brown groundmass, holding white kaolinized feldspars, dark brown decomposed hornblende crystals, and a little mica. It is closely allied to some of the modern rocks from the Cordilleras. The groundmass is now kaolinized, forming a dirty-white mass holding secondary quartz and feldspar, as well as long narrow ferrite masses. These latter appear to have been formed from the hornblende fibres, so frequently seen in the allied rocks from the Cordilleras. The groundmass has now through its alteration a spherulitic structure.

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* Proc. Am. Acad., XIII. 283.

No. 524 is a more compact rock of like character. Its groundmass is kaolinized and holds the quartz and feldspar alteration products. It is filled with grains and masses of ferrite probably derived from hornblende. The feldspar is so decomposed that it cannot be told whether it is plagioclase or orthoclase. Nos. 526 and 529 are like No. 523, while No. 530 is more allied to No. 524.

No. 527 has a more coarsely crystalline, granitoid structure, showing under the lens a reddish and grayish brown groundmass, holding elongated brownish-black hornblende crystals. In the thin section it is seen to be composed of feldspar, magnetic iron, hornblende, and some quartz. The feldspar is greatly altered, and is now composed of intergrowths of feldspar and quartz, giving rise in it to a structure resembling that of graphic granite, or much of that figured as belonging to the Eozoön Canadense. The quartz is all secondary, and the hornblende altered to reddish or yellowish brown ferruginous masses.

No. 528 is a fine-grained granitoid trachyte (granite porphyry), but in the thin section the feldspar is seen to be so altered and filled in with secondary quartz, containing full and bubble-bearing fluid, and vapor cavities, that the section resembles that obtained from some fragmental rocks. No. 525 is a rock of similar character.

Nos. 538, 539, 541, and 544 are good examples of some of the sandstones on the river below the melaphyr. No. 538 is seen in the section to be composed of quartz and trachytic detritus.

Below and at the base of the falls the dip remains the same as before, N. 45° W. 10°, but above this locality the inclination varies, rising from 15° to 18° between the first and second falls. In some places a quaquaversal dip was seen. Some five falls exist in the river, and at the last or upper fall the melaphyr was found. The dip of the sandstone has now increased to some 20°, but still dips northwest, and the first trappean flow is seen to overlie and greatly indurate and alter it. This immediately underlying sandstone (537) is filled in with little reticulated veins of calcite, a kaolin-like material, etc., and in general resembles the baked sandstone found underlying the trap on the western side of Keweenaw Point. Microscopically, it is seen to be composed of the *débris* of the trachytes previously described. This sandstone was seen within three inches of the melaphyr, and although there may have been some sliding motion between the two, as the contact was not seen, yet the induration of the sandstone, its dip, and its relations to the melaphyr, prove that it underlies the latter, which flowed over it. This, then, with evidence obtained on the Douglas Houghton River, settles the long-disputed question of the relative age of the traps and eastern sandstones of Lake Superior. The dip of the melaphyr is about the same as that of the sandstone. Immediately above this thin lava sheet, a conglomerate comes in, forming the fifth fall. The base of this conglomerate is composed of a fine-grained detritus formed from the melaphyr and trachyte, and holds numerous pebbles of the melaphyr, as well as of the other rocks (531, 532, 533, 534, 535, 536). Immediately overlying this conglomerate is another melaphyr flow, and we have here on the eastern side a repetition of the same alternate bands of melaphyr and sandstone that occur on the western side.

It is to be remembered that Mr. Agassiz, in conjunction with Mr. L. G. Emerson, the well-known mining engineer of Hancock, and at one time assistant on Prof. Pumpelly's geological survey, found below the Douglass Houghton Falls pebbles of the melaphyr (amygdaloid) in the sandstone; and from this the conclusion was drawn that the sandstone was younger than the trappean formation. At the time of our visit to this locality, we had no knowledge of Mr. Agassiz's observations,* except from the general statement of Prof. Pumpelly.† It will be seen that no localities were given by Prof. Pumpelly, although he confirms Mr. Agassiz's statements. The falls were said by Mr. Agassiz to be located at the junction of the sandstone and trap, while on both sides of the ravine the horizontal sandstone beds were traced up to the falls. Our examination showed that immediately below the falls sandstone and conglomerate exist, dipping N. 45° W. 25° (504, 505). While the majority of pebbles were of the usual character, one grayish granitoid pebble (506) containing epidote was obtained. This has suffered the same *graphic* alteration in its feldspar that No. 527 has. Much of the feldspar is seen to be triclinic. Otherwise than its containing more quartz, its characters are in the main like No. 527. The sandstone, at its junction with the overlying trap, is much indurated and altered, and specimens were obtained showing the junction of the two (507, 508, 509, 510, 511). As the sandstone underlies the trap, it is of necessity the prior-formed rock. We suppose that this was the locality at which Messrs. Agassiz and Emerson obtained their specimens of melaphyr in the conglomerate. If so, it is easily enough explained, for conformably underlying this sandstone is another sheet of melaphyr, then more sandstone, again more melaphyr, and so on, all conformably underlying one another as much as they do anywhere within the trappean belt, or can do, on account of their origin. Whether this is the spot or not, it is evident from the language of Mr. Agassiz's paper that the gentlemen took their facts and drew their conclusions while they were within the trappean belt, not having found the junction at all, it being some distance below the falls, not at them. From Prof. Pumpelly's statement it would seem that he had made the same mistake, as likewise Mr. Foster had done years before.* Something more is necessary to be observed than simply to find a sandstone or conglomerate on the eastern side ; it is necessary to prove that it is part of the eastern sandstone, and not a bed intercalated in the trap. The sandstone and melaphyr, a short distance below the dip last given, has a dip of 20°, still inclining to the northwest. The last melaphyr sheet underlies a sandstone dipping at this angle, and is itself underlaid by another sandstone having the same dip. In other words, the last trap on the eastern side of Keweenaw Point is a thin flow of only some two feet in thickness, at this locality, and is interbedded between sandstones which immediately above and below it have the same dip that it has. As the river is followed downwards the dip gradually declines in steepness, although still dipping northwest. The last dip measured was N. 45° W. 5°. The conglomerate and sandstone below the first basaltic flow, i. e. that nearest to Torch Lake, has apparently been acted upon by hot waters. The sandstone has been leached, its feldspathic constituents largely changed into clay, and the pebbles are greatly altered and kaolinized. The constitution of the sandstone and conglomerate appears to have been originally the same as that of the bands interlaminated with the trap, except so far as they are modified by the detritus of the latter. In many places this hot-water action has bleached the sandstone and leached out of it all the argillaceous material, leaving it a nearly pure siliceous sandstone (518). This has also converted some of the finer beds into a fine-grained, highly argillaceous sandstone or arenaceous clay, these beds having probably arrested the progress of much of the argillaceous material (519, 520). This water action would certainly account for the absence of fossiliferous remains in the sandstone exposed to its effects. Considerable mica in fine scales was seen in the argillaceous bands. Specimens of the various pebbles were taken from the conglomerate (513, 514, 515, 516, 517). No. 517 is a grayish and reddish-brown granitoid-looking rock, and under the lens is apparently composed of feldspar holding quartz grains. Microscopically it is seen to be a crystalline aggregate of decomposed feldspar and hornblende, holding much secondary quartz. The quartz is arranged in the feldspar in the *graphic* or eozoön form, which makes the decomposed feldspar a most beautiful object in polarized light. The contrast between the brilliantly polarizing quartz and the feebly polarizing, kaolinized feldspar substance is thus strongly brought out. The quartz appears to have been deposited from the decomposed feldspar itself, which breaks up into silica and the kaolin-like material. The quartz contains full fluid cavities, those with bubbles, and vapor cavities. The hornblende is in the usual reddish-brown decomposed masses. Some magnetite was seen. This rock is most probably a decomposed old trachyte, although it would doubtless be regarded as a granite porphyry by most lithologists. No. 515 is a similar but more feldspathic rock. No. 513 is similar to No. 527, and Nos. 514 and 516 are like No. 524. Many pebbles or lenticular masses of clay were seen, that are apparently decomposed pebbles of the conglomerate.

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* Proc. Bost. Soc. Nat. Hist., XI. 244-246.

† Geol. of Mich., Part II. p. 3.

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* Senate Docs., 1st Sess. 31st Cong., 1849 – 50, III. 782 ; Executive Docs., 1st Sess. 31st Cong., 1849 – 50, IX. Doc. 69, p. 67.

In the sandstone quarry at the head of the *incline* on the Hecla and Torch Lake Railroad, the sandstone layers have been regarded as being nearly horizontal. The joint planes that form the floors of the quarry are nearly so, having only a slight dip to the northwest; but these joint planes cannot be the bedding planes, for we find on close examination that numerous layers of coarser material, pebbles, clay masses, etc. occur in the rock. These layers extend for long distances through the sandstone, and are always parallel, having the same dip, which is N. 45° W. 15°. These of course, from their character and regularity, must mark the old planes of bedding, while the generally supposed bedding planes are secondary joint planes cutting the bedding planes at a small angle. This sandstone (456, 457, 458, 459, 461, 462, 463, 464) has been leached and acted upon by water the same as that below the Douglass Houghton Falls, and its feldspathic material converted into clay or entirely removed. Part of the materials composing the sandstone, especially in the coarser portions, are similar to those in the sandstone at Marquette. The quartz grains are partly water-worn, but a large proportion are seen to be short crystals formed of the hexagonal prism, terminated on both ends by the pyramid, or the usual form found in the acidic porphyritic rocks. It appears, then, as the facets of these crystals are comparatively unworn, that they were derived from the destruction or decomposition of trachytic and rhyolitic rocks (granitic and quartz porphyries), the feldspathic material having been removed since by water, leaving a quartzose sandstone. It is a question worthy of examination whether any other sandstones have been formed from acidic volcanic material, from which nearly all the other parts of the rock have been removed by percolating waters; especially as other sandstones have been said to be composed of quartz crystals.

As the sedimentary rocks are more and more studied, the evidence comes on every side that, like this sandstone, while their formation may have taken as long as is generally supposed, they may have been deposited very rapidly, some being composed of old volcanic scoria, ashes, and mud. In very many other cases the supposed sedimentary rocks are really volcanic flows or intrusive masses. In the sandstone just described the same masses of clay (460) occur as on the Douglass Houghton River, and they may arise here, as there, from the decomposition of the enclosed feldspathic or argillite pebbles. Another solution of the question of the origin of some of these would be the filling in of cavities formed by the removal of some other material, by the argillaceous material brought from above. This is suggested by the finding of stalactites of the sandstone (464) extending down into the clay. At the spring just above the quarry the sandstone (521) is red spotted with white, and dips N. 45° W. 14°.

The relations of the traps to the interbedded sandstones and conglomerates have been given before. The trap has, when covered by the sandstone, been worn by water, and the latter rock deposited upon it. The sandstone, in its lower portion, holds to a greater or less extent the *débris* of the underlying trap. Should we apply then rigorously the logic of the Michigan and Wisconsin geologists, we should make a distinct geological age every time a bed of sandstone or conglomerate was formed over any of the trappean flows. Their method of reasoning would prove that the Keweenaw series is made up of some forty to sixty different geological ages, every one as distinct from the age of the rocks underlying it, as they would make the Potsdam sandstone distinct from the Keweenawan.

Besides the melaphyr pebbles and detritus, the conglomerates are composed of similar pebbles to those found in the conglomerate of the eastern side. No. 552, from the Hecla mine, has a dark reddish-brown groundmass, holding white and pinkish feldspars and quartz. In the thin section it is seen to be an old rhyolite, and to have flowed as a lava, for it possesses the contorted, twisted, fluidal structure seen in so many of the rhyolites from the Cordilleras, with which it can be perfectly parallelized, except so far as the alteration has removed some of its original characters. It shows the same twisting and interweaving of the brownish-colored glassy material that they do; its quartzes are fissured and rounded, and penetrated by the base the same as they are in modern rhyolites; and in like manner they are seen to be of prior origin to the consolidation of the lava. The quartz here, as in the rhyolites, plays the same part that olivine does in the basalts and hornblende in the andesites. It is a foreign ingredient, of prior origin to the lava, and has not crystallized out of it.* The quartz contains stone, vapor, and fluid inclusions. The majority of the fluid and vapor (empty) cavities are arranged along fissures, as if they had been formed by hot waters depositing silica in fissures. The feldspar is thoroughly kaolinized, and, like the quartz, is frequently in rounded and broken pieces, which show that it was formed prior to the consolidation of the lava. Considerable secondary quartz occurs in the groundmass, but the base affects polarized light but little, if at all.

It is intended to figure this section in connection with some of the rhyolites of the Cordilleras, for if ever a section showed conclusive proof that the view, that volcanic action did not commence until the Tertiary epoch, is fallacious, this is one. No. 553, from the same locality, has a similar, but lighter brown and less abundant groundmass. This holds numerous yellowish-red and clay-colored feldspars, as well as much quartz. This rock, like the preceding, is an old rhyolite (quartz porphyry). The base is an olive-brown, felty mass, holding opacite grains, quartz, feldspar, and decomposed black hornblende. The characters of the quartz and feldspar are like those in the preceding rock. On the edges and in the cleavage planes of the feldspar, copper has been deposited in both of these rocks. No. 554, from the same locality, is a grayish-red, granitoid rock. In the thin section this is seen to be like the more granitoid trachyte pebbles found towards Torch Lake, and described before. This contains much secondary quartz, and a little that appears to be primary. The feldspars are decomposed, and the quartz is so arranged in them that they show the *graphic* characters. The rock holds numerous rows of ferrite globules, which rows are arranged in a radiate form, giving to the slide a spherulitic appearance. A little of the feldspar is seen to be triclinic. No. 562 is a pretty brown rhyolite (felsite) with a very compact groundmass, holding some minute feldspars. This was taken from the conglomerate of the Osceola mine. The feldspars are seen to be largely triclinic, while the groundmass is a brownish devitrified aggregate of secondary quartz, feldspar, and ferrite. The finer portions of the Calumet conglomerate are seen microscopically to be composed of the rhyolitic and trachytic detritus, the former predominating. In one of the enclosed fragments, quartz was seen containing several of the double pyramidal inclusions so common in the quartz of modern rhyolites.

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* Bull. Mus. Comp. Zoölogy, V. 277-282.

On the Mineral Point Railroad, about three fourths of a mile from Hancock, the melaphyrs were seen to be interbedded with a number of conglomerates. Certain pebbles intended to represent the different varieties were collected. No. 419 is a very compact, fine-grained, reddish-brown rhyolitic rock (felsite). In the thin section it shows a compact groundmass, made up of the devitrification products : quartz, feldspar, and ferrite. No. 420 has a reddish-brown groundmass, holding reddish feldspars and black hornblendes. The feldspar is seen in the thin section to be much decomposed, and part holds quartz in the *graphic* form in it. Some retains traces of its triclinic character, but all has the same hematite alteration product that is common in orthoclase. The hornblende crystals of this old trachyte are changed to ferrite and viridite. Besides the quartz, ferrite, and viridite, as another alteration product epidote occurs. This mineral is quite abundant. Magnetite and some apatite were seen. No. 421 has a very compact, reddish-brown felsitic groundmass, holding feldspar crystals. This old trachyte (feldspar porphyry, or felsite), in the thin section, is seen to have a reddish-brown groundmass, composed of alteration quartz, feldspar, and ferrite. The porphyritically enclosed feldspars are largely plagioclase. No. 422 is another trachyte (felsite porphyry), containing numerous reddish and greenish-gray feldspar crystals, held in a dark, reddish-brown groundmass. Microscopically the feldspars and groundmass are seen to be greatly decomposed and kaolinized. Viridite, epidote, opacite, and quartz occur as alteration products. This rock is closely allied to the andesites.

No. 423 is a very fine-grained reddish granite, composed of feldspar, quartz, hornblende, and biotite. Considerable alteration quartz, ferrite, and opacite were seen. The feldspars are much altered. The quartz contains fluid, vapor, and stone cavities, also numerous trichites.

No. 424 is a brick-red granitoid trachyte (granite porphyry). The feldspar is much decomposed, and has the alteration quartz arranged in the *graphic* form. The rock shows through its alteration a somewhat spherulitic structure. This arises from the radiating arrangement of the alteration products in the groundmass. The sandstone found associated with the conglomerates is made up of the fine detritus of these trachytic and rhyolitic rocks, mixed to a greater or less extent with the basaltic material.

The sandstone and conglomerate west of the traps were studied in several places, especially at Copper Falls, west of Houghton, and northwest of Hancock. At the latter locality, marked *slates* on the map of the Portage Lake district, by A. R. Marvine and L. G. Emerson,* or, in other words, at the bottom of the ravine below the curve, at the end of the heavy grade of the Mineral Range Railroad, they were examined the most thoroughly, as that locality seemed to be the most probable place to find fossils, if any existed in the sandstone. Although our search was unsuccessful, we think it very probable that, if one had the appliances for more extended work, fossils might be found here. The contact of the sandstone with the traps was not seen here. In the parts nearest the latter it is a coarse, reddish-brown sandstone, composed of reddish feldspar, quartz, and basaltic detritus (387, 388, 409). It is composed of the same materials as the sandstone, interbedded with the basalts, although it perhaps has more basaltic detritus than they do. The enclosed pebbles appear to be trachyte (felsite porphyry), of the same character as those found within the trappean district near Hancock (389).

As we recede from the traps, the sandstone becomes finer, or passes into a shale composed of the same materials (390, 391). Lenticular or rounded concretions occur in the shale, which closely resemble pebbles (392). Little spherical concretions of sand, similar to those described by Messrs. Foster and Whitney,† occur here (393, 394). In some of the coarser portions of the sandstone, interstratified with the shale, little fragments and scales of argillite were seen (395). Some of the shale is fine and earthy (398), and in places shows rain-drop impressions (399, 400), ripple-marks (400, 401, 402), and mud-flows (403, 404, 405, 408). About two miles above Hancock the sandstone was formerly quarried, on the shore of the lake. Its dip is N. 30° W. 23°. The dip of the conglomerates nearer Hancock, interstratified with the traps, is 40°. Any inequality of the lava flows or of the shore deposits of sand and pebbles would give rise to a change in the dip of succeeding beds.

West of Houghton, sandstone and conglomerate of the same general character was observed dipping N. 45° W. 30°. It is probable that the Laumontite ("red Zeolitic mineral") which Dr. Rominger describes as occurring here, and also forming the cement of the conglomerates elsewhere,‡ is the red feldspar of the trachytes (felsites). The material of which the western sandstone is composed, and its junction with the trap, all show that it is of the same geological age as the trappean rocks, although younger in point of time.

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* Geol. of Mich., I., Atlas, Plate XIV. *a*.

† Executive Docs., 1st Sess. 31st Cong., 1849 – 50, IX., Doc., 69, p. 112.

‡ Geol. of Mich., I., Part III. pp. 97, 98.

The sandstones and conglomerates are evidently beach-worn, and are simple shore deposits. Whence the trachytic and rhyolitic material came, is a subject worthy of future investigation. They were evidently lavas that had been erupted prior to the basaltic flows, and a knowledge of their original position, as well as tracing the different kinds to their present resting-place, would give us considerable knowledge of the physical geography of that old sea. The conglomerates occurring interbedded with the traps would of necessity be more limited and variable than the lava flows themselves, for they could only be deposited upon the part of the lava that lay along the shore line, and even there only in those places where the conditions were favorable to the accumulation and retention of detritus. The amount of conglomerate would in some measure depend upon the length of time elapsing between the basaltic flows; but on account of the local nature of the conglomerates, their absence at any particular spot does not prove the immediate following of the succeeding eruption, or that no conglomerate exists elsewhere between the two lavas.

While we were able to do nothing to prove the geological age of the eastern sandstone, it seems that Dr. Rominger has brought forward evidence conclusively establishing the correctness of Messrs. Foster and Whitney's view, based on its stratigraphical relations, that it was of Potsdam age. We have shown sufficient evidence to prove that in the parts visited by us the eastern sandstone conformably underlies the trap, and that, as held by Messrs. Foster and Whitney, the eastern and western sandstones, and the traps lying between them, are of the same geological age. Whether the idea is correct or not, as held by these gentlemen, that the eastern sandstone at the Bohemian and Porcupine Mountains is younger in order of time of deposition than the traps, and was originally continuous with the western sandstone, we cannot say, having never studied the sandstone in either locality. It is, however, plain that such is not the relation of the eastern sandstone in the vicinity of Torch Lake to either the traps or western sandstone. It is also evident that the volcanic action began gradually the same as it ended, and produced similar alternations of trap and sandstone on both sides of Keweenaw Point.

The Veins and Copper Deposits.

At some time after the sandstones, conglomerates, and traps were laid down, extensive and deep-seated fissures were formed, generally extending, in the district north of Portage Lake, across the beds. These fissures seem to have been formed by powerful movements of different parts of the rocks, causing their cross fracture and dislocation. The movements have been repeated from time to time, causing a rubbing, grinding, breaking, and polishing of the parts adjacent to the fissures, forming numerous slickensides. These movements would not cause irregular and secondary fracturing to any great extent after the main fissures had been formed, in the heavy-bedded diabases or the sandstones; but in the scoriaceous and thin-bedded melaphyrs, the tendency to yield to the pressure was much greater, and the rock adjacent to the fissures was broken up to a considerable extent. During the time of the fracturing, and since, the fissures served as channels for water. In the scoriaceous and easily decomposable melaphyrs the water served by its decomposition of the adjacent rock to widen the fissures, but in the diabases, although their composition was the same, their structure and the absence of much glass prevented the same results occurring. The sandstones and conglomerates, from their being principally composed of trachytic and rhyolitic material, and from their structure, suffered little, compared with the melaphyrs, from vein formation.

In many localities the evidence is strong that the percolating waters were hot; in others, as remarked by Marvine, no sign exists that it was above the temperature of the present day. Water penetrated with greater or less readiness through the traps themselves, causing their decay and alteration, while the substances taken up in solution by it were deposited in the fissures, cells, and other open spaces in the rock. The filling of pre-existing cavities and fissures gave rise to the amygdaloidal structure of the traps and the vein material; the decomposition of the trap, and its replacement of some materials by others, gave rise to the pseudo-amygdaloidal structure. This structure exists not only in the non-scoriaceous or non-cellular portions, but also in the truly scoriaceous or cellular portions.

All or nearly all of the material filling the veins and adjacent traps appears to have been derived from the decomposition of the traps themselves, and not brought in from extraneous sources,— this decomposition being brought about by the medium of the percolating waters, whose course seems, in many cases at least, to have been downwards. The partial decomposition of the fractured portions of the traps and the filling of the interspaces by the vein matter give rise to the great width which the veins sometimes attain, — thirty feet. While the veins in the narrower portions are often filled with pure vein material, in the wider parts they are composed of a breccia of decomposed trap cemented by vein matter. The comby and sheet structure of the veins, the class of minerals enclosed, the decomposition of the associated melaphyr, — in fact, all their characters, — point out that these are true fissure veins filled by segregation.

In the veins the copper is found intimately mixed with the gangue, or in sheets or irregular masses. The copper in the sheet form, as is much of the mass copper of the veins, extends downwards, or has its sides approximately parallel with the walls of the vein. Oftentimes the sheet bifurcates, holding some of the gangue or melaphyr between its parts (818). On cutting the mass copper it is not uncommon to find completely enclosed in it masses of melaphyr, quartz, calcite, or other of the vein materials. The association, structure, and the relations of the copper to the vein material and to the traps, all show that it was deposited in the same way the vein matter and secondary materials in the traps were.

The melaphyrs adjacent to the veins are often impregnated, in the decomposed portions, with copper, as well as the usual secondary deposits. In certain cases it has paid to take out the parts adjacent to the vein, but fallacious have proved and will prove the hopes of continous profitable mining based on these local deposits. Vein mines associated with local deposition of copper in the adjacent traps have been and are now so abundant at Lake Superior that it would be invidious for us to specify any one of them. In the vicinity of Portage Lake the old lava flows themselves are mined. No trace or sign of a true fissure vein exists in most of the beds that are mined in this locality. The mining is confined to work upon unstratified deposits, the same as if some of the more cellular and deeply buried lavas of Vesuvius or Etna were for any reason mined. These melaphyrs have been greatly acted upon by hot waters, which have decomposed them, and deposited the copper in an irregular, "bunchy" manner. On the Isle Royale lode this hot-water action is very strongly marked, the original basalt being now greatly altered, and filled with epidote and quartz, or other minerals (377, 378, 379, 380, 381, 382, 383, 384).

In others the action is not so strongly marked, but more evenly distributed throughout the bed, as for instance the Quincy. All these bed mines have their deposits distributed in a very irregular manner, requiring much dead work as a neccessary concomitant of the way in which the copper was deposited.

Another variety of the bed mining is that known as *ash-bed* mining. As stated before, the ash-bed is a more scoriaceous flow than the generality of the melaphyrs to which it belongs, and has the copper deposited throughout its mass, not rich, but quite uniform, or subject to certain well-marked laws of variation. So far as could be ascertained, the ash-bed shows no sign of hot-water action at Copper Falls, but rather evidence that the copper was deposited from a cold, or, at most, only a warm solution. The rock is but little changed, and retains part of the signs of its fluid state, almost as well marked as they are in some comparatively recent lavas. In other mines in which a transverse fissure vein and a melaphyr (amygdaloid) is mined, the impregnation of the melaphyr with copper seems to be dependent upon its proximity to the vein, being rich near the vein, but growing poorer as it recedes from it. Here the conditions are reversed: the ash-bed is apt to be poorer near the veins than at a distance from them. Where the overlying trap sent down tongues into the ash-bed, the latter became indurated, and consequently but little copper was deposited in it at these places.

The Atlantic mine at Portage Lake is supposed to be on the ash-bed, or a similar formation. This mine was visited, and the rock found to be similar to that of the ash-bed, except much harder. This rock has, like the rock in the other mines at Portage Lake, been subjected to much more intense metamorphic action than the ash-bed at Copper Falls. The copper here, however, is quite evenly distributed, and all of the bed is stoped out and sent to the stamp-mill. So far as could be told by lithological evidence, the Atlantic mine is on the same bed as the Copper Falls mine, or on a bed having the same origin. The action of thermal waters on the former accounts for its present difference from the latter.

The induration of any rock does not apparently depend upon the question of the heat of the water which acts upon it, but upon the deposition of mineral matter in the rock by the water, and on the hardness of the deposited minerals. No mineral matter need be brought in; the induration requires only that the chemical constituents should reunite into minerals of greater hardness. These alterations are always a passage from unstable to more stable compounds, in the conditions to which the rocks are subjected. Glass is the most unstable form in which any of the rock constituents can be; but the melaphyrs, from their origin and the conditions to which they were subjected at the time of consolidation, must have possessed a vast amount of glassy material. Hence they were most liable to decomposition and alteration, which might or might not result in induration. At Copper Falls no general induration exists, except, for instance, where quartz has been deposited, but at the Atlantic the induration is general. We have seen, that the action of hot waters on the sandstone at Torch Lake gave rise to the reverse of induration, as its action was that of removal, and not of deposition.

The last form of copper deposit in the district visited by us is that of the conglomerate mines. The beds of conglomerate are composed, as before said, of rhyolitic, trachytic, and basaltic pebbles and detritus. In some of these conglomerates, as the Calumet and Hecla, the cement has been removed, and its place, or the original interspaces, filled with copper. In some cases melaphyr pebbles have been largely removed, and their places filled with copper, giving rise to boulder-like forms (471). These conglomerates, then, are simply old sea-beach deposits, and, like the amygdaloids and ash-beds, are not veins, and cannot properly be so called. They must of necessity partake of the characteristics of their origin, the same as veins do of theirs.

The copper has been found throughout the district underlying heavy beds of trap or a series of smaller ones; in fact, in the parts visited by us, experience has shown that copper in abundance was only found where trap in large amounts overlaid the vein or bed. The copper was found filling, at the Calumet and Hecla mine, the joints of the overlying trap, and extending as a continuous sheet through fissures at right angles to one another. At Copper Falls spikes of copper extend downwards out of the overhanging trap into the ash-bed. These are generally large at the upper end, and pointed at the lower. Like them are the secondary depositions of calcite, in this trap, in long, spike-like forms, that here and elsewhere have been taken for fossils. These features prove that the copper came from above downwards, and that it was deposited after the jointing of the trap. In fact, the evidence is strong that all the alteration and fissuring of the rocks, and the deposition of the copper and associated minerals, took place after the western sandstone had been deposited. The above facts indicate that the copper was derived from finely disseminated copper distributed throughout the lava, as modern lavas have been known to contain it. If it was derived from the sandstone, as advocated by Bauerman and later by Pumpelly, it should be found in connection with the sandstone; but such is not the case. The farther from the sandstone, and the nearer the heavy beds of trap, the larger have been the deposits of copper, e. g. Cliff, Central, and Calumet and Hecla. The conglomerate of this last mine was not the home of the copper; it is simply the place where it has been deposited by secondary agencies. The statement now kept up for some thirty years in Dr. Dana's works, that the copper is chiefly found at the junction of the sandstone and trap, is a good illustration of how an error once in a text-book cannot be eradicated.

Conclusions.

The general geological structure of the region visited by us is, then, in general, as follows. Beginning on the southeastern side of Keweenaw Point we find a sandstone and conglomerate overlaid by melaphyr. This melaphyr is again overlaid by sandstones and conglomerates, principally the latter. The alternations of melaphyr, diabase, sandstone, and conglomerate, with the melaphyr and diabase largely predominating, continue across the centre of the Point, forming its backbone. As the northwestern side is approached, the sandstones and conglomerates increase, while the melaphyr and diabase diminish, until a purely sandstone formation is reached.

All these rocks taken together make one geological formation, and have been laid down successively one upon the other, in order, going from the east towards the west. These rocks are known to form the same series by their conformably overlying one another. These traps are old lava flows, spread out over the then existing surface along a shore line. They have flowed the same as modern basaltic lavas do under like conditions, and retain the same characters, except so far as they have been modified by the agencies to which they have been subjected since their outflow. They are known to be old lava flows by their baking and indurating the immediately underlying rock, by their sending dikes and tongues down into this rock, by their scoriaceous character on the upper surface, by their signs of having flowed, and by their microscopic characters. That they were laid down before the overlying rock is shown by their producing no effect upon it; by their presenting on the upper surface only the irregularities and rounded knobs that such surfaces are known to have, especially when they have been worn; by rounded pebbles and boulders of the underlying traps, being enclosed in the overlying conglomerates; by the absence of fragments of the overlying rock in the underlying one; and by the absence of any characters showing intrusion of the traps between the different beds. The extent of these old lava flows, except as seen along their upturned edges, is not known, for they have been followed by mining along their incline some 2,100 feet only. Judging from their length, their width must be considerable. In thickness they partake of the same irregularities which any similar flow has. Locally the thinner and more scoriaceous flows are known as "amygdaloids," the thicker and more compact ones as "traps," and the thickest one on the western side as "greenstone." The difference between these several forms of old basalt seems to be occasioned only by the variable amount of lava erupted at different times, and the slightly different conditions to which the flows were subjected.

Most of these old basalts are directly covered by succeeding flows, following after greater or lesser intervals of time; but part, as remarked above, are covered by conglomerates and sandstones. These conglomerates and sandstones show, by the rounded and water-worn character of their constituent pebbles and grains, that they are beach deposits. The surface of the underlying basalt is smoothed as by water action. The overlying conglomerate is made up at its base of basaltic mud and pebbles, derived from the underlying rock, and mixed with the felsitic mud and pebbles of which the conglomerates are chiefly composed. The trappean mud and pebbles diminish, or are entirely wanting, as we recede from the underlying trap. That the basalt is a metamorphosed sandstone, as is often contended by mining men, is disproved by the facts given above, and by the further facts, that there is no gradual but an abrupt, passage between the two; that all fragments of sandstone caught up by the trap are baked and indurated by the heat, but show no signs of passage; and, lastly, that it would demand the conversion of an acidic rock into a basic one.

From the conditions given above it would not be surprising to find the lava flows locally limited at any point, and partially or even entirely denuded, and replaced, in part or as a whole, by conglomerates and sandstones. This would depend, of course, upon the position of the shore line, and upon the conditions to which the basalt was subjected during the time of its flow, or since. A still greater variability is to be looked for in the conglomerates and sandstones. All these conditions are to be taken into consideration in the mining of these old lava flows and their associated conglomerates.

In the Portage Lake and Keweenaw Point districts there are mined at present four forms of deposits: —

1. Melaphyrs of an amygdaloidal character, known as "amygdaloid" mines, which have been subjected to hot-water action, and whose deposits of copper are "bunchy" and irregular. These are in no sense veins or lodes, and the Quincy and the Shelden and Columbian mines are good examples.

2. Ash-bed mines, which are truly melaphyr or "amygdaloid" ones, but the melaphyr is of a more scoriaceous character, as was pointed out above, of which the Copper Falls (in part) and the Atlantic mines are examples.

3. The conglomerate or true bed mines, like the Calumet and Hecla.

4. The true fissure vein mines, like the Central, Phœnix, and Copper Falls (in part).

The first two forms should be classed as one.

It is an established rule that a mineral vein, in passing from one bed of rock into another of a different nature, is apt to vary in width and contents. Such variations in dimensions and gangue have been repeatedly found in this district, as the different beds are comparatively narrow. As might be expected, the variation is not so strongly marked in the different melaphyrs, since they are all rocks of the same composition and origin, differing only in texture, thickness, and crystallization. One and the same vein may then vary in width, from a mere seam to thirty or more feet, as is the case with the "Owl Creek Vein," as mined at Copper Falls. Under these conditions one cannot judge with any certainty, from the appearance of the vein at one point, what will be its width or character at another. The decision must be based on probabilities only. In places the fissure may be filled with true vein material, while in other parts, especially in the wider portions, it may be filled with fragments of the melaphyr, cemented together by vein matter. The width of the vein will depend largely upon the readiness with which the country rock yielded to the crushing and grinding force, and to the action of the percolating waters. We should expect, then, the veins to be mere nominal fissures in the sandstones, conglomerates, and heavy "greenstone," but to be more or less well marked in the "amygdaloids" and "traps."

The filling of the veins and of the cavities in the melaphyrs, it appears, was accomplished by the same agencies. The amygdaloidal structure of the melaphyr is owing to the filling with mineral matter, with greater or less completeness, gas cavities formed at the time of the lava flow. Besides the true amygdaloidal structure, there are numerous cases of pseudo-amygdaloidal structure. This last arises from the alteration of the formerly solid parts of the melaphyr, and is to be found not only in the compact portions (lower) of the rock, but also in the scoriaceous parts (upper). These amygdules and pseudo-amygdules are composed of quartz, calcite, epidote, prehnite, laumontite, analcite, apophyllite, datolite, chlorite, delessite, etc., etc. The constituents of these minerals were derived from the decomposition of the melaphyr, and deposited through the agency of the percolating waters. The vein materials are the same as those of the amygdules, and they are of like derivation and deposition. The copper is found forming a constituent part of the amygdules in many places, as well as of the vein-stone, and it would seem to have been deposited in a like manner. Until we know more about the occurrence of the copper, all theories regarding its origin should be held with a loose grasp, and dropped as the facts developed may require thereafter. It is held by some that the copper was derived from solutions of the metal in sea-water, precipitated by decaying organic matter, and accumulated in the sandstones, shales, and conglomerates of the series. It was then taken up by the percolating waters, and deposited in the places in which it is now found. A second view is that the copper was originally finely disseminated through the lava at the time of its outflow, and has since been locally concentrated by percolating waters in the amygdules, veins, and conglomerate beds. The writer inclines to the latter view, believing that this theory is more in accordance with the facts observed by him than the former one. The final concentration and precipitation seem to be connected in some way with the oxides of iron, which are abundant in the melaphyr and in the detritus of it and of the felsite pebbles, which form the principal portion of the conglomerate. The copper seems to have needed for its deposition some of the following conditions: rocks that were porous and cellular; those whose parts were easily removed by the percolating waters, as the mud forming the cementing material of the conglomerates; the open spaces of veins and fissures; and rocks acted upon by hot waters. The copper, when not distributed through the whole bed, is found principally in the upper portion. Whatever may be our views respecting the sources of the copper, it is evident that it was deposited by aqueous agencies, and that the general course of the solution was downwards. The best vein-stones, so far as observed, are datolite, prehnite, and calcite. Laumontite does not seem to have much mass copper associated with it. While large masses of copper were seen at the Central mine associated with calcite, a similar association is rarely found in the Owl Creek vein at Copper Falls. The best vein-stone there has been datolite. The prehnite here seems in depth to yield to datolite.

The theories of the igneous origin of the veins, and of the igneous deposition of the copper in them, have been so ably refuted in the various papers referred to here that it is unnecessary to discuss them; but owing to the great weight of Professor Dana's name, we cannot pass over his theory without saying that the supposed facts on which it is based do not exist in the Copper district, he having raised the superstructure on the errors of Messrs. Houghton and Jackson, never having visited the region himself.

As in the Iron district, so in the Copper district, the writings of Messrs. Foster and Whitney remain the best and most accurate exponents, as they were the first of value, of the geology of the country, and of the ore deposits studied by us, so far as they were known at that time. All work since, so far as it stands the test of examination, sustains their views and establishes the accuracy of their observations, except in a few particulars. Mr. A. R. Marvine's work stands next in order of value and geological ability shown.

Professor Pumpelly deserves all credit for his microscopic examinations of the old basaltic rocks of the district, and for the extent and thoroughness with which he has applied and carried out the investigations and theories of Messrs. Whitney, Müller, and Bauerman, in his "Paragenesis and Derivation of Copper and its Associates on Keweenaw Point"; but his stratigraphical work was not worthy of the name, and served only to obscure the true relations of the rocks. The volcanic origin of the rocks was proved by Marvine five years before, by Foster and Whitney twenty-eight years before, and announced by Hubbard thirty-two years before Pumpelly accepted it.

Our work proves that the Keweenawan system has no foundation except in insufficient observation and the application of stratigraphical methods and assumptions that will not bear examination. The difficulty here, as in the Iron district, has been in the methods, and in the assumption that certain observations proved that which they did not.

I desire to extend my thanks for favors received while in the Iron and Copper districts to Charles E. Wright, M. E., State Commissioner of Mineral Statistics; Per Larsen, M. E. of the Jackson mine; Agents C. H. Hall, of the Lake Superior mine, William Sedgwick, of the Barnum, D. H. Bacon, of the McComber; Capts. James Pascoe, of the Champion, and Peter Pascoe, of the Republic; also to Mr. David Morgan, President of the Republic Iron Company; to Captain Cliff, and L. G. Emerson, M. E.

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CAMBRIDGE, MASS., May 18th, 1880.

APPENDIX.

List of Papers and Works relating to the Geology, Mineralogy, and Physical Geography of Lake Superior.

THE writer does not claim that this list contains all that has been written on these subjects relating to Lake Superior, for it is simply the outgrowth of a desire, arising after part of the body of this paper was written, to save others the trouble of doing over again the work that he had already done. It is not intended as a *bibliography* in the approved modern sense, but simply to serve as a stepping-stone to those who may hereafter desire to take up the study of this most interesting region. Papers and works, which from their titles appear to belong to different departments or to other localities, have been given, when matter relating to these subjects or this region, as the case may be, has been found in them. All papers given here that the writer has not seen are marked with an asterisk (*).

In the preceding text, in quoting from the various authors referred to, the intention has been to make the spelling, punctuation, and italics identical with the originals, which accounts for certain peculiarities that the reader will observe.

Agassiz, Alexander.

On the Position of the Sandstone of the Southern Slope of a Portion of Keweenaw Point, Lake Superior. Proc. Bost. Soc. Nat. Hist., 1867, xi. 244 - 246.

Agassiz, Louis.

On the Fishes of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1848, i. 30 - 32.

The Terraces and Ancient River Bars, Drift, Boulders, and Polished Surfaces of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1848, i. 68 - 70.

On the Origin of the Actual Outlines of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1848, i. 79.

Remarks upon the Unconformability of the Palæozoic Formations of the United States. Proc. Am. Assoc. Adv. Sci., 1851, vi. 254.

On Marcou's "Geology of North America." Am. Jour. Sci., 1859, (2,) xxvii. 134 - 137.

Agassiz, Louis, *and* **J. Elliot Cabot.**
Lake Superior. Its Physical Characters, Vegetation, and Animals. Boston, March, 1850. 428 pp. Edinburgh New Phil. Jour., 1850, (2,) xlix. 25–33, 398, 399; Am. Jour. Sci., 1850, (2,) x. 83–101.

Akermann, H. W.
Die Kupferführenden Schichten am Lake Superior. Sitzungs-Berichte der naturwissenschaftlichen Gesellschaft Isis in Dresden, 1875, pp. 101–105.

Alger, Francis.
Pseudomorphic Crystal of Native Copper from Copper Falls Mine, Lake Superior. Proc. Bost. Soc. Nat. Hist., 1861, viii. 170, 171.

Andrews, Israel D.
On the Trade and Commerce of the British North American Colonies, and upon the Trade of the Great Lakes and Rivers. Sen. Docs., 1st Sess. 32d Cong., 1851–52, xi., No. 112, 906 pp. Contains a report by C. T. Jackson.

Anonymous.
Michigan: its Commerce and Resources. Hunt's Merch. Mag., 1842, vi. 333–348.

The Copper Mines of Lake Superior. Hunt's Merch. Mag., 1846, xiv. 439–443.

Ancient Mining on Lake Superior. Hunt's Merch. Mag., 1848, xix. 663.

Elevation of an Island in Lake Superior. Ann. of Sci. Discov., 1851, 255.

The Copper and Iron Region of Lake Superior. Review of the Work of F. C. L. Koch. Mining Mag., New York, 1853, (1,) 261–268.

The Silver of the Lake Superior Mineral Region. Mining Mag., New York, 1853, (1,) i. 447–454, 612, 613; ii. 82, 83.

Notice of a Geological Map of the United States, etc., by Jules Marcou. Am. Jour. Sci., 1854, (2,) xvii. 199–206.

Mineral Wealth of the Lake Superior District. Ann. of Sci. Disc., 1855, 309, 310.

Mineral Region of Lake Superior. Mining Mag., 1858, (1,) ii. 248–252.

Great Mass of Native Copper. Min. and Smelt. Mag., 1864, vi. 25, 26; Am. Jour. Sci., 1864, (2,) xxxvii. 431.

Canada. A Geographical, Agricultural, and Mineralogical Sketch. Published by authority of the Bureau of Agriculture. Quebec, 1865, 33 pp.

Barnes, George O.
See Charles T. Jackson.

Bartlit, William, *and* **David Tod.**
Mineral Regions of Lake Superior. Senate Docs., 1st Sess. 29th Cong., 1845–46, iv., No. 160, pp. 20–25.

Bayfield, H. W.
Outlines of the Geology of Lake Superior. Trans. of the Lit. and Hist. Soc. of Quebec, 1829, i. 1–43.

On the Junction of the Transition and Primary Rocks of Canada and Labrador. Quart. Jour. Geol. Soc., 1845, i. 450–459.

Beaumont, Elie de.

Age of the Sandstone of Lake Superior. Bull. Soc. Geol. France, 1849 – 50, (2,) vii. 209.

See Louis Cordier.

Bell, Robert.

Geology of Lake Superior and Nipigon. Geol. of Canada, 1866 – 69, pp. 313 – 364.

Report on the Country North of Lake Superior, between the Nipigon and Michipicoten Rivers. Geol. Surv. of Canada, Rep. of Prog., Ottawa, 1870 – 71, pp. 322 – 351.

Report on the Country between Lake Superior and the Albany River. Geol. Surv. of Canada, Rep. of Prog., Montreal, 1871 – 72, pp. 100 – 114.

Report on the Country between Lake Superior and Lake Winipeg. Geol. Surv. of Canada, Rep. of Prog., Montreal, 1872 – 73, pp. 87 – 111.

The Mineral Region of Lake Superior. Canadian Nat. and Geol., 1875, (2,) vii. 49 – 51.

Report on an Exploration in 1875, between James Bay and Lakes Superior and Huron. Geol. Surv. of Canada, Rep. of Prog., 1875 – 76, pp. 294 – 342.

Report on Geological Researches North of Lake Huron and East of Lake Superior. Geol. Survey of Canada, Rep. of Prog., 1876 – 77, pp. 193 – 220.

Bell, William H.

Mineral Lands of the Upper Mississippi. Executive Docs., 1st Sess. 28th Cong., 1843 – 44, iii., No. 43, 52 pp.

Bigsby, John J.

A List of Minerals and Organic Remains occurring in the Canadas. Am. Jour. Sci., 1824, (1,) viii. 60 – 88.

Notes on the Geography and Geology of Lake Superior. Quart. Jour. Sci. and Arts, 1824 – 25, xviii. 1 – 34, 228 – 269.

On the Erratics of Canada. Quart. Jour. Geol. Soc., 1851, vii. 215 – 238, with map.

On the Physical Geography, Geology, and Commercial Resources of Lake Superior. Edinburgh New Phil. Jour., 1852, liii. 55 – 62; Am. Jour. Sci., 1852, (2,) xiv. 138; Proc. of the Royal Institution, 1852, i. 154 – 162.

On the Organic Contents of the Older Metamorphic Rocks: a Review and a Classification. Edinburgh New Phil. Jour., 1863, (2,) xvii. 171 – 197.

Billings, E.

General Geology. Canadian Nat. and Geol., 1856, i. 1 – 25.

Blake, William P.

Review of a Portion of the Geological Map of United States and British Provinces, by Jules Marcou. Am. Jour. Sci., 1856, (2,) xxii. 383 – 388.

The Mass Copper of Lake Superior Mines and the Method of Mining it. Trans. Am. Inst. Min. Engineers, 1875, iv. 110 – 112.

Blandy, John F.

Topography with especial Reference to the Lake Superior Copper District. Trans. Am. Inst. Min. Engineers, 1871, i. 75 – 82.

Stamp Mills of Lake Superior. Trans. Am. Inst. Min. Eng., 1874, ii 208 – 215.

The Lake Superior Copper Rocks in Pennsylvania. Trans. Am. Inst. Min. Eng., 1879, vii. 331 – 333, 336.

See C. P. Williams.

Borie, Jules.

* Notice sur le Lac Supérieur et ses Mines de Cuivre de la Rive Americaine. St. Etienne Bull. Soc. Industr., 1860, vi. 233 – 284; vii. 185 – 252; viii. 271, 272; Allgem. Berg. u. Hütten. Zeitung, 1862, iv. 448 – 450, 457 – 460, 469 – 471.

Bradley, Frank H.

On a Geological Chart of the United States east of the Rocky Mountains, and of Canada. Am. Jour. Sci., 1876, (3,) xii. 286 – 291.

Bristol, T. W.

See Jacob Houghton, Jr.

Brooks, T. B.

Geological Survey of Michigan, with Maps, 1869 – 1873, i.; Part I., Iron-bearing Rocks, 319 pp.; Part II., Copper-bearing Rocks, R. Pumpelly and A. R. Marvine, 143 pp.; Part III., Palæozoic Rocks, Charles Rominger, 105 pp; ii. 298 pp., contains papers by Messrs. Brooks, Julien, Wright, Jenney, and Tuttle.

On the youngest Huronian Rocks south of Lake Superior and the Age of the Copper-bearing Series. Am. Jour. Sci., 1876, (3,) xi. 206 – 211.

Classified List of Rocks observed in the Huronian Series, south of Lake Superior, etc. Am. Jour. Sci., 1876, (3,) xii. 194 – 204.

See T. C. Chamberlain.

Brooks, T. B., *and* **R. Pumpelly.**

On the Age of the Copper-bearing Rocks of Lake Superior. Am. Jour. Sci., 1872, (3,) iii. 428 – 432.

Brown, A. J.

The Formation of Fissures and the Origin of their Mineral Contents. Trans. Am. Inst. Min. Eng., 1874, ii. 215 – 219.

Burt, William A., *and* **Bela Hubbard.**

Reports of William A. Burt and Bela Hubbard on the Geography, Topography, and Geology of the U. S. Surveys of the Mineral Region of the South Shore of Lake Superior for 1845, etc. In the "Mineral Region of Lake Superior," by J. Houghton, Jr., and T. W. Bristol. Detroit, 1846. Senate Docs., 1st Sess. 29th Cong., 1845 – 46, vii. Doc. 357, 29 pp.; 1st Sess. 31st Cong., 1849 – 50, iii. 803 – 842.

Geology and Topography of the District south of Lake Superior, 1846. Senate Docs., 1st Sess. 31st Cong., 1849 – 50, iii. 842 – 932.

See Charles T. Jackson, *and* Jacob Houghton, Jr.

Cabot, J. Elliot.

See Louis Agassiz.

Callender, John A.
The Lake Superior Copper Mines. Mining Mag., 1854, ii. 249 – 253.

Calvert, John.
On the Decomposition of Rocks and the Recomposition of their Metallic Constituents. Mining Mag., 1854, iii. 371 – 376.

Campbell, J. B.
See John Stockton.

Cass, Lewis.
Letter from Governor Cass, of Michigan, on the Advantage of Purchasing the Country upon Lake Superior where Copper has been found. Senate Docs., 2d Sess. 18th Cong., 1824 – 25, No. 19, 2 pp.

Chamberlain, T. C.
Geology of Wisconsin, 1873 – 1877, II., 768 pp. with maps. Reports by Messrs. I. A. Lapham, O. W. Wight, T. C. Chamberlain, R. D. Irving, C. E. Wright, and Moses Strong. 1873 – 1879, III., 763 pp. with maps. Reports by Messrs. R. D. Irving, R. Pumpelly, A. A. Julien, C. E. Wright, E. T. Sweet, T. B. Brooks, A. Wichmann, T. C. Chamberlain, and T. S. Hunt.

Channing, William T.
See Charles T. Jackson.

Chapman, E. J.
Popular Exposition of the Minerals and Geology of Canada. Canadian Jour., 1860, (2,) v. 1 – 19, 168 – 182, 517 – 531; 1861, vi. 149 – 165, 425 – 455, 500 – 518; 1862, vii. 108 – 121; 1863, viii. 17 – 33, 111 – 127, 185 – 216, 437 – 462; 1864, ix. 1 – 10.

On Some Minerals from Lake Superior. Canadian Jour., 1865, (2,) x. 406 – 411.

On Some Minerals from Lake Superior. Phil. Mag., 1866, (4,) xxxi. 176 – 180.

Notes on the Silver Locations of Thunder Bay. Canadian Jour., 1869, (2,) xii. 218 – 226.

An Outline of the Geology of Ontario, based on a Subdivision of the Province into six Natural Districts. Canadian Jour., 1875, (2,) 580 – 588.

On the Leading Geological Areas of Canada. Canadian Jour., 1876, (2,) xv. 92 – 122.

Chester, Albert H.
On the Percentage of Iron in Certain Ores. Trans. Am. Inst. Min. Eng., 1875, iv. 219.

Clarke, Robert D.
Notes from the Copper Region. Harper's New Monthly Mag., 1853, vi. 433 – 448, 577 – 588.

Clarke, T. C.
The Great Lakes. Atlantic Monthly, 1861, vii. 226 – 235.

Claypole, E. W.

On the Pre-Glacial Geography of the Region of the Great Lakes. Canadian Nat. and Geol., 1878, (2,) viii. 187 – 206.

Pre-Glacial Formation of the Beds of the Great American Lakes. Canadian Nat. and Geol., 1879, ix. 213 – 227.

Clinton, De Witt.

On Certain Phenomena of the Great Lakes of America. Trans. New York Lit. and Phil. Soc., ii., Part I. 1 – 33.

Cordier, Louis.

Note sur une Masse de Cuivre natif provenant des Rives du Lac Supérieur, aux États-Unis d'Amérique. Louis Cordier and Elie de Beaumont. Comptes Rendus, 1849, xxviii. 161 – 163; Leonhard's Jahrbuch, 1849, p. 470.

Courtis, W. M.

The North Shore of Lake Superior as a Mineral-bearing District. Trans. Am. Inst. Min. Eng., 1877, v. 473 – 487.

Credner, Hermann.

Die Gliederung der eozoischen (vorsilurischen) Formationsgruppe Nord-Amerikas. Zeits. Gesam. Naturwiss., Giebel, 1868, xxxii. 353 – 405.

Beschreibung einiger charakteristischer Vorkommen des gediegenen Kupfers auf Keweenaw Point am Oberens See Nord-Amerika's. Leonhard's Jahrbuch, 1869, 1-14.

Die vorsilurischen Gebilde der "Obern Halbinsel von Michigan" in Nord-Amerika. Zeit. Deut. Geol. Gesell., 1869, xxi. 516 – 554.

Gewaltige Kupfermassen am Lake Superior. Leonhard's Jahrbuch, 1870, 86.

Ueber nordamerikanische Schieferporphyroide. Leonhard's Jahrbuch, 1870, 970 – 984.

Elemente der Geologie. *1st ed. 1872, *2d ed. 1872, 3d ed. 1876, 699 pp., *4th ed. 1880.

Crosby, William O.

On a Possible Origin of Petrosiliceous Rocks. Proc. Bost. Soc. Nat. Hist., 1879, xx. 160 – 169.

Contributions to the Geology of Eastern Massachusetts. Occasional Papers of the Bost. Soc. Nat. Hist., 1880, iii. 286 pp., with map.

Cunningham, Walter.

Report of Walter Cunningham, late Mineral Agent on Lake Superior. Jan. 8, 1845. Senate Docs., 28th Cong. 2d Sess., 1844 – 45, vii., No. 98, 5 pp.

Dana, James D.

System of Mineralogy. 1st ed., New Haven, 1837, 671 pp.; 2d ed., New York, 1844, 633 pp.; 3d ed., New York, 1850, 711 pp.; 4th ed., New York, 1854, 853 pp.; 5th ed., New York, 1868, 827 pp.

Manual of Mineralogy. New Haven, 1857, 456 pp.

Review of Marcou's "Geology of North America." Am. Jour. Sci., (2,) 1858, xxvi. 323 – 333.

Reply to Prof. Agassiz on Marcou's "Geology of North America." Am. Jour. Sci., 1859, xxvii. 137 – 140.

Manual of Geology. New York. 1st ed., 1862, 800 pp.; 2d ed., 1874, 828 pp.; 3d ed., 1880, 911 pp.

Manual of Mineralogy and Lithology. New York, 1878, 474 pp.

Davies, D. C.

Metalliferous Minerals and Mining, London, 1880, 432 pp.; Copper Rocks, pp. 149 – 164; Iron Ores, pp. 274, 275.

Dawson, John W.

On the Geological Structure and Mineral Deposits of the Promontory of Maimanse, L. Sup. Canadian Nat. and Geol., 1857, ii. 1 – 12.

Dawson, S. J.

Report on the Exploration of the Country between Lake Superior and the Red River Settlement, etc. S. J. Dawson and H. Y. Hind. Toronto, 1858. 424 pp., with maps.

Report on the Exploration of the Country between Lake Superior and the Red River Settlement. Toronto, 1859. 45 pp., with maps.

Papers relative to the Exploration of the Country between Lake Superior and the Red River Settlement. S. J. Dawson, Henry Y. Hind, and others. Blue Book, 1859, Sess. 2, xxii., 163 pp., with maps.

D'Archiac, A.

Progrès de la Géologie, 1848, ii., Terrain Quaternaire, 369, 370; viii., Formation Triassique, 635 – 644.

Dearborn, H. A. S.

On the Variations of Level in the Great North American Lakes, with Documents. Am. Jour. Sci., 1829, (1,) xvi. 78 – 94.

Delafield, Joseph.

Notice of new Localities of Simple Minerals along the North Coast of Lake Superior, etc. Ann. Lyc. of Nat. Hist., 1824, i. 79 – 81.

Delesse, A.

Mines de Fer des États-Unis. Annales des Mines, 1857, (5,) xii. 805 – 841.

Deroux, H.

Die Kupfergruben des Oberen See's (Lake Superior). * Journal des Mines, 1860, vii.; Berg. u. Hütten. Zeit., 1861, pp. 305 – 307, 329 – 331.

Desor, Edward.

Rain-Drop and Air-Bubble Impressions. Edward Desor and J. D. Whitney. Proc. Bost. Soc. Nat. Hist., 1849, iii. 200, 201; 1851, iv. 131 – 133; Proc. Am. Assoc. Adv. Sci., 1851, v. 74.

Sand Dunes and Ripple Marks on Lake Superior. Proc. Bost. Soc. Nat. Hist., 1849, iii. 207, 208; 1851, iv. 41, 42.

Des Alluvions Marines et Lacustres, et du Terrain erratique de l'Amérique du Nord. Bull. Soc. Geol. France, 1849 – 50, (2,) vii. 623 – 630. Sur les Drifts de l'Amérique du Nord, 1851 – 52, ix. 94 – 96. Sur la Carte géologique du Lac Supérieur, ix. 280, 281. Note sur le Terrain quaternaire de l'Amérique du Nord, 1851 – 52, ix. 281 – 285. Sur le Terren de Transition et quaternaire des États Unis, ix. 312 – 322. Ann. Sci. Discov., 1853, 269 – 272.

Clay and Drift Deposits on Lake Superior. Proc. Bost. Soc. Nat. Hist., 1850, iii. 235, 236; Am. Jour. Sci., 1852 (2,) xiii. 93 – 109; Zeit. Deut. Geol. Gesell., 1852, iv. 669 – 679.

Drift Striæ on Lakes Superior and Michigan. Proc. Bost. Soc. Nat. Hist., 1850, iii. 242.

"Cross Formation" of Sandstone on Lake Superior. Proc. Bost. Soc. Nat. Hist., 1850, iii. 341.

Parallelism of Mountain Chains in America. Proc. Bost. Soc. Nat. Hist., 1850, iii. 380 – 382; Am. Jour. Sci., 1851, (2,) xii. 118 – 120.

Origin of the Drift of Lake Superior. Proc. Bost. Soc. Nat. Hist., 1851, iv. 28, 29.

Dunes on the Upper American Lakes. Proc. Bost. Soc. Nat. Hist., 1851, iv. 41, 42.

Lake Superior. On the Silurian Rocks of the Lake Superior Land District. Proc. Am. Assoc. Adv. Sci., 1851, v. 64, 65.

Post-Pliocene of the Southern States and its Relation to the Laurentian of the North and the Deposits of the Valley of the Mississippi. Am. Jour. Sci., 1852, (2,) xiv. 49 – 59.

See Foster *and* Whitney.

Dieffenbach, Otto.

Bemerkungen über den Kupferbergbau in den Vereinigten Staaten von Nord-Amerika. Berg. u. Hütten. Zeit., 1858, pp. 47, 48, 66 – 68, 75, 76.

Disturnell, John.

The Great Lakes or Inland Seas of America. New York, 1863, 192 pp. and map.

Douglas, James.

The Native Copper Mines of Lake Superior. Quart. Jour. Sci., 1874, xi. 162 – 180; Canadian Nat. and Geol., 1874, (2,) vii. 318 – 336.

Dupee, J. A.

Ash-bed of the Phœnix Mine. Proc. Bost. Soc. Nat. Hist., 1855, v. 279, 280.

Dutton, T. R.

Observation on the Basaltic Formation on the Northern Shore of Lake Superior. Am. Jour. Sci., (2,) 1847, iv. 118, 119.

Eames, Henry H.

* Geological Reconnoissance of the Northern, Middle, and other Counties of Minnesota. St. Paul, 1866. 58 pp.

Report of the State Geologist, Henry H. Eames, on the Metalliferous Region bordering on Lake Superior. St. Paul, 1866, 23 pp.

Egleston, Thomas.

Boracic Acid in Lake Superior Iron Ores. Trans. Am. Inst. Min. Eng., 1876, v. 131, 132.

Copper Mining on Lake Superior. Trans. Am. Inst. Min. Eng., 1877, vi. 275 - 312.

The Conglomerates of Lake Superior, and the Methods of Dressing Copper. Trans. Am. Inst. Min. Eng., 1877, v. 606 - 611.

Emmons, Ebenezer.

Copper Mines of Lake Superior. American Geology, Albany, 1855, pp. 171 - 173.

Foster, J. W.

On Certain Phenomena connected with the Rise and Fall of the Waters of the Northern Lakes. Proc. Am. Acad., 1849, ii. 131 - 136; Ann. Sci. Discov., 1850, pp. 245, 246; Edinburgh New Phil. Jour., 1850, xlix. 172.

Catalogue of Rocks, Minerals, etc., collected by J. W. Foster. Smithsonian Report, 1854, 384 - 387.

On the Antiquity of Man in North America. Trans. Chicago Acad. Sci., 1867 - 69, pp. 227 - 257.

Ancient Mining by the Mound-builders, in the "Pre-historic Races of the United States." Chicago, 1873, pp. 361 - 374.

Foster, J. W., *and* **J. P. Kimball.**

Geology and Metallurgy of the Iron Ores of Lake Superior. New York, 1865, 97 pp., with maps.

Foster, J. W., *and* **J. D. Whitney.**

Synopsis of the Explorations of the Geological Corps in the Lake Superior Land District in the Northern Peninsula of Michigan. Senate Docs., 1849 - 50, iii., No. 5, 605 - 626.

Report on the Geology and Topography of the Lake Superior Land District. Part I., Copper Lands. Executive Docs., 1st Sess. 31st Cong., 1849 - 50, ix., No. 69, 244 pp. with map; Am. Jour. Sci., 1851, (2,) xii. 222 - 239. Part II., The Iron Region, together with the General Geology, contains additional Reports by James Hall, Edward Desor, Charles Whittlesey, and W. D. Whitney. Senate Docs., Special Sess. 32d Cong., 1851, iii., No. 4, 406 pp. with maps; Am. Jour. Sci., 1853, (2,) xv. 295, 296; 1854, (2,) xvii. 11 - 38, 181 - 194.

Report on the Iron District of Lake Superior. Senate Docs., 2d Sess. 31st Cong., 1850 - 51, ii., No. 2, 147 - 152.

Aperçu de l'ensemble des Terrains Siluriens du Lac Supérieur. Bull. Soc. Géol. France, 1850, (2,) viii. 89 - 100.

On the Azoic System, as developed in the Lake Superior Land District. Proc. Am. Assoc. Adv. Sci., 1851, v. 4 - 7.

On the Age of the Sandstone of Lake Superior, with a Description of the Phenomena of the Association of Igneous Rocks. Proc. Am. Assoc. Adv. Sci., 1851, v. 22 - 38.

On the Different Systems of Elevation which have given Configuration to North America, with an attempt to Identify them with those of Europe. Proc. Am. Assoc. Adv. Sci., 1851, v. 136 - 151.

On the Origin and Stratigraphical Relations of the Trappean Rocks of Lake Superior. Ann. Sci. Discov., 1861, 285.

Frazer, Persifor, Jr.

The Lake Superior Copper Rocks in Pennsylvania. Trans. Am. Inst. Min. Eng., 1879, vii. 336 – 339.

Fullerton, T. M.

St. Louis River. Minn. Hist. Coll., 1850 – 56, i. 139 – 143.

Geinitz, H. B.

Alexander Winchell: über geologische Verhältnisse in Michigan. Leonhard's Jahrbuch, 1876, pp. 438 – 440.

Genth, Frederick A.

Contributions to Mineralogy. Am. Jour. Sci., 1859, (2,) xxvii. 400; xxviii. 246 – 255; 1862, xxxiii. 190 – 206.

Gray, A. B.

Report of A. B. Gray on Mineral Lands of Lake Superior. Executive Docs., 1st Sess. 29th Cong., 1845 – 46, vii., No. 211, 23 pp., with map.

See John Stockton.

Greeley, Horace.

Process of Working a Lake Superior Copper Mine. Hunt's Merch. Mag., 1848, xix. 559, 560.

Hager, A. D.

Ancient Mining on the Shores of Lake Superior. Atlantic Monthly, 1865, xv. 308 – 315.

Hall, C. W.

See S. F. Peckham *and* N. H. Winchell.

Hall, James.

On the Silurian System of the Lake Superior Region. Am. Jour. Sci., 1854, (2,) xvii. 181 – 194.

On the Potsdam Sandstone. Sixteenth Ann. Rep. of the Regents of the Univ. of New York. Appendix D. Albany, 1863, pp. 210 – 220.

See Foster *and* Whitney.

Hanchett, Augustus H.

* Report on the Geology of Minnesota. 1864, 82 pp.

Hayes, A. A.

Datolite from Lake Superior. Proc. Bost. Soc. Nat Hist., 1859, vii. 348, 349, 354; 1862, viii. 62 – 64.

Hector, James.

On the Geology of the Country between Lake Superior and the Pacific Ocean, etc. Quart. Jour. Geol. Soc., 1861, xvii. 388 – 445.

See John Palliser.

Henwood, William J.

On the Native Copper of Lake Superior. On Metalliferous Deposits and Subterranean Temperature. Part. I, pp. 385 – 489; Trans. Geol. Soc. of Cornwall, vol. viii., Part I., 1871, pp. 385 – 489.

Hill, S. W.

Copper Falls Mine. Mining Mag., 1854, ii. 668 – 672.

Hind, Henry Y.

Report on the Exploration of the Country between Lake Superior and the Red River Settlement. 1858, 425 pp., with maps.

Report on the Assiniboine and Saskatchewan Exploring Expedition. 1859, 201 pp., with maps.

Narrative of the Canadian Exploring Expeditions. London, 1860, i. 494 pp., ii. 472 pp.

See S. J. Dawson.

Hitchcock, Edward.

Outline of the Geology of the Globe. Boston, 1853, 162 pp., with maps.

Hodge, James T.

On the Mineral Region of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1849, ii. 301 – 308; Ann. Sci. Discov., 1850, 260, 261.

Houghton, Douglass.

Report of Doctor Houghton on the Copper of Lake Superior. Nov. 14, 1831. In the Discovery of the Source of the Mississippi, by H. R. Schoolcraft, pp. 287 – 292. New York, 1834.

First Annual Report on the Geology of Michigan, 1838. Lanman's History of Michigan, 1839, 347 – 366; Am. Jour. Sci., 1838, (1,) xxxiv. 190 – 192.

Second Annual Report of the State Geologist. Senate Docs., Michigan, 1839, 264 – 294; Am. Jour. Sci., 1841, (1,) xl. 136.

Third Annual Report of the State Geologist, 1840. Senate Docs., Michigan, 1840, 66 – 157.

Fourth Annual Report of the State Geologist. Joint Docs., Michigan, 1841, 472 – 607.

Fifth Annual Report of the State Geologist. Joint Docs., Michigan, 1842, 436 – 441.

Metalliferous Veins of the Northern Peninsula of Michigan. Am. Jour. Sci., 1841, (1,) xli. 183 – 186; Trans. of the Assoc. Am. Geol. and Nat., 1840 – 42, pp. 35 – 38; Edinburgh New Phil. Jour., 1842, xxxiii. 201, 202.

Copper on Lake Superior. Am. Jour. Sci., 1844, (1,) xlvii. 107, 132.

See T. B. Brooks, J. Houghton, Jr., J. H. Relfe, *and* H. R. Schoolcraft.

Houghton, Jacob, Jr.

The Ancient Copper Miners of Lake Superior. Iron, 1876, (N. S.,) viii. 168, 169, 199; Swineford's Copper, Iron, and other Material Interests of Lake Superior. Marquette, 1876, pp. 78 – 89.

Houghton, Jacob, Jr., *and* T. W. Bristol.

Mineral Region of Lake Superior. Detroit, 1846, 109 pp. and map. Contains Reports by Messrs. Burt, Hubbard, D. Houghton, and Stannard.

Hubbard, Bela.

See William A. Burt, J. Houghton, Jr., *and* C. T. Jackson.

Hughes, G. W.

The Working of Copper Ore. Senate Docs., 1st Sess. 28th Cong., 1843 – 44, v., No. 291, 58 pp.

Hunt, T. Sterry.

On some Ores of Nickel from Lake Superior. Am. Jour. Sci., 1855, (2,) xix. 417, 418.

On some Points in American Geology. Am. Jour. Sci., 1861, xxxi. 392 – 414; Canadian Nat and Geol., 1861, vi. 81 – 105.

Contributions to Lithology. Am. Jour. Sci., 1864, (2,) xxxvii. 248 – 266; xxxviii. 91 – 104, 174 – 185.

The Origin of Metalliferous Deposits. Trans. Am. Inst. Min. Eng., 1872, i. 413 – 426.

The Geognostical History of the Metals. Trans. Am. Inst. Min. Eng., 1873, i. 331 – 336.

Geognosy of the Appalachians and the Origin of Crystalline Rocks. Proc. Am. Assoc. Adv. Sci., 1871, xx. 1 – 59.

The Geology of the North Shore of Lake Superior. (Supplementary Note.) Trans. Am. Inst. Min. Eng., 1873, ii. 58, 59.

Chemical and Geological Essays. Boston, 1874, 489 pp. Revised Edition, Salem, 1878.

The Development of Our Mineral Resources. Harper's Magazine, 1875, li. 82 – 94.

Azoic Rocks, Part I., 1878. Second Geological Survey of Pennsylvania. E. 253 pp.

The Lake Superior Copper Rocks in Pennsylvania. Trans. Am. Inst. Min. Eng., 1879, vii. 333 – 336, 339.

The History of some Pre-Cambrian Rocks in America and Europe. Am. Jour. Sci., 1880, (3,) xix. 268 – 283.

See T. C. Chamberlain *and* W. E. Logan.

Irving, Roland D.

On some Points in the Geology of Northern Wisconsin. Trans. Wisc. Acad. Sci., 1873 – 74, ii. 107 – 119.

On the Age of the Copper-bearing Rocks of Lake Superior; and on the Westward Continuation of the Lake Superior Synclinal. Am. Jour. Sci., 1874, (3,) viii. 46 – 56.

Note on the Age of the Crystalline Rocks of Wisconsin. Am. Jour. Sci., 1877, (3,) xiii. 307 – 309.

Note on the Stratigraphy of the Huronian Series of Northern Wisconsin; and on the Equivalency of the Huronian of the Marquette and Penokee Districts. Am. Jour. Sci., 1879, (3,) xvii. 393 – 398.

See T. C. Chamberlain.

Jackson, Charles T.

Minerals from Lake Superior. Proc. Bost. Soc. Nat. Hist., 1844, i. 203; 1845, ii. 57, 58.

Nature of Minerals accompanying Trap Dykes which interrupt various Rocks. Proc. of the Sixth Ann. Meet. of the Assoc. of Am. Geol. and Nat., New Haven, 1845, 29 – 31.

On the Copper and Silver of Kewenaw Point, Lake Superior. Am. Jour. Sci., 1845, (1,) xlix. 81 – 93; Proc. of the Sixth Ann. Meet. of the Assoc. of Am. Geol. and Nat., New Haven, 1845, 53 – 60.

Sur le Gisement de Cuivre et d'Argent natifs des Bords du Lac Supérieur. Comptes Rendus, 1845, xx. 593 – 595; Bull. Soc. Geol. France, 1844 – 45, (2,) ii. 317 – 319; L'Institute, 1845, xx. 593 – 595; Leonhard's Jahrbuch, 1845, pp. 479, 480.

The Copper and Silver Mines of Lake Superior. Proc. Bost. Soc. Nat. Hist., 1846, ii. 110 – 114; Am. Jour. Sci., 1846, (2,) ii. 118, 119.

Report on the Mineral Lands of Lake Superior. Contains Reports by Messrs. Locke, Channing, McNair, and Whitney. Senate Docs., 1st Sess. 30th Cong., 1847 – 48, ii., No. 2, 175 – 230.

Ores and Minerals from Lake Superior. Proc. Bost. Soc. Nat. Hist., 1847, ii. 256, 259, 260.

Mineral Lands of Lake Superior. Contains Reports of J. W. Foster and J. D. Whitney. Senate Docs., 1848 – 49, 2d Sess. 30th Cong., ii., No. 2, 153 – 163; Executive Docs., 1848 – 49, 2d Sess. 30th Cong., iii., No. 12, 153 – 163.

Report on the Progress of the Geological Survey of the Mineral Lands of the United States in Michigan. Senate Docs., 1848 – 49, 2d Sess. 30th Cong., ii., No. 2, 185 – 191; Executive Docs., 1848 – 49, 2d Sess. 30th Cong., iii., No. 12, 185 – 191.

Copper of the Lake Superior Region. Am. Jour. Sci., 1849, (2,) vii. 286, 287.

Lake Superior. Observations on the Mirage seen on Lake Superior in July and August, 1847. Proc. Am. Assoc. Adv. Sci., 1849, ii. 143 – 146; Proc. Bost. Soc. Nat. Hist., 1849, iii. 169.

Remarks on the Geology, Mineralogy, and Mines of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1849, ii. 283 – 288.

On the Geological Structure of Keweenaw Point. Proc. Am. Assoc. Adv. Sci., 1849, ii. 288 – 301.

Remarques sur la Géologie du District Métallifère du Lac Supérieur. Bull. Soc. Geol. France, 1849 – 50, vii. 667 – 673.

Report on the Geological and Mineralogical Survey of the Mineral Lands of the United States in the State of Michigan. Contains Reports by Messrs. Jackson, Foster, Whitney, Locke, Barnes, Burt, Hubbard, and others. Senate Docs., 1st Sess. 31st Cong., 1849 – 50, No. 5, iii. 371 – 935; Am. Jour. Sci., 1851, (2,) xi. 147, 148.

Remarques sur la Géologie du District Métallifère du Lac Supérieur, suivi d'une courte Description de quelques-unes des Mines de Cuivre et d'Argent. Extrait par M. Delesse. Annales des Mines, 1850, (4,) xvii. 103 – 115.

Age of the Lake Superior Sandstone. Proc. Bost. Soc. Nat. Hist., 1848, iii. 76, 77; 1850, p. 228; 1860, vii. 396-398.

On Jacksonite. Proc. Bost. Soc. Nat. Hist., 1850, iii. 247, 248.

Former Level of Lake Superior. Proc. Bost. Soc. Nat. Hist., 1850, iii. 292.

On the Age of the Sandstones of the United States. Proc. Bost. Soc. Nat. Hist., 1850, iii. 335-339.

Analyses of Pitchstone Porphyry from Isle Royale, etc. Am. Jour. Sci., 1851, (2,) xi. 401, 402; Proc. Bost. Soc. Nat. Hist., 1851, iv. 39, 40.

Rain-Drop and Air-Bubble Impressions. Proc. Bost. Soc. Nat. Hist., 1851, iv. 131, 132.

Geology, Mineralogy, and Topography of the Lands around Lake Superior. Senate Docs., 1851-52, 1st Sess. 32d Cong., xi. 232-244. In Andrews's Report.

Igneous Origin of Calcite Veins. Proc. Bost. Soc. Nat. Hist., 1853, Feb. 17, iv. 308, 309.

Ueber den Metallführenden Distrikt am Obern See im Staate Michigan. Karsten's Archiv., 1853, xxv. 656-667.

Catalogue of Rocks, Minerals, and Ores collected during the years 1847 and 1848, on the Geological Survey of the United States Mineral Lands in Michigan. Collected by Charles T. Jackson. Smithsonian Report, 1854, pp. 338-367.

Observations sur quelques Mines des États-Unis et sur le Grès Rouge du Lac Supérieur. Comptes Rendus, 1854, xxxix. 803-807.

Trap Dikes. Proc. Bost. Soc. Nat. Hist., 1856, vi. 23, 24.

On the Ash-bed and the Origin of the Copper. Proc. Bost. Soc. Nat. Hist., 1855, v. 280, 281; 1859, vii. 31.

Thermal Waters. Proc. Bost. Soc. Nat. Hist., 1859, vii. 45-47.

Domeykite from Lake Superior. Proc. Bost. Soc. Nat. Hist., 1861, viii. 258.

Sur les Mines de Cuivre du Lac Supéreur et sur un Nouveau Gisement d'Étain dans l'État du Maine. Compes Rendus, 1869, lxix. 1082, 1083.

See James H. Relfe.

Jackson, Charles T., *and* **J. B. Perry.**

Glacial Origin of Lake Superior. Proc. Bost. Soc. Nat. Hist., 1870, xiv. 73-75.

Jenney, F. B.

See T. B. Brooks.

Julien, Alexis A.

See T. B. Brooks *and* T. C. Chamberlain.

Keating, William H.

Narrative of an Expedition to the Source of St. Peter's River, etc., performed in the Year 1823. 2 vols. i. 458; ii. 248, and app. 156. London, 1825.

Kimball, J. P.

On the Iron Ores of Marquette, Mich. Am. Jour. Sci., 1865, (2,) xxix. 290-303.

See J. W. Foster.

Kneeland, Samuel.

Copper of Lake Superior. Proc. Bost. Soc. Nat. Hist., 1857, vi. 283, 284.

Koch, F. C. L.

Kupfer- und Eisenerze am Lake Superior. Zeit. Deut. Geol. Gesells., 1851, iii. 355 – 358.

Die Mineral-Regionen der oberen Halbinsel Michigan's (N. A.) am Lake Superior und die Isle Royal. Studien des Gottingischen Vereins bergmännischer Freunde, von J. F. L. Hausmann. 1854, vi. 1 – 248; The Mining Magazine, New York, 1853, i. 261 – 268.

Lachlan, R.

On the Periodical Rise and Fall of the Lakes. Am. Jour. Sci., 1855, (2,) xix. 60 – 71, 164 – 176; xx. 45 – 53.

Lapham, Increase A.

The Penokie Iron Range. Wisc. State Agr. Soc. Trans., 1858 – 59, v. 391 – 400, with map.

See T. C. Chamberlain.

LeConte, John L.

On Coracite, a new Ore of Uranium. Am. Jour. Sci., 1874, (2,) iii. 173 – 175.

Lesley, J. P.

Iron Manufacturer's Guide. New York, 1859, 772 pp., with maps.

Locke, John.

Geology of Porter's Island and Copper Harbour. Trans. Am. Phil. Soc., 1844, ix. 311, 312, (pp. 305 – 315,) with maps.

Geology and Magnetism. Smithsonian Contributions, 1851, iii., Art. I., pp. 17 – 29.

Catalogue of Rocks, Minerals, Ores, and Fossils collected by John Locke. Smithsonian Report, pp. 1854, 367 – 383.

See Charles T. Jackson.

Logan, William E.

North Shore of Lake Superior. Geol. Surv. of Canada, Rep. of Prog., 1846 – 47, pp. 5 – 46.

Remarks on the Mining Region of Lake Superior, and a Report on Mining Locations claimed on the Canadian Shores of the Lake. Montreal, 1847, 31 pp., with maps.

Report on the North Shore of Lake Huron. Geol. Surv. of Canada, Montreal, 1849, 51 pp.

On the Age of the Copper-bearing Rocks of Lakes Superior and Huron. Report of the Brit. Assoc. Adv. Sci., 1851, xxi., Trans. Sections, 59 – 62; Am. Jour. Sci., 1852, (2,) xiv. 224 – 229.

Remarks on the Fauna of the Quebec Group of Rocks and the Primordial Zone of Canada. Am. Jour. Sci., 1861, (2,) xxxi. 216 – 220.

Considerations relating to the Quebec Group and the Upper Copper-bearing Rocks of Lake Superior. Canadian Nat. and Geol., 1861, vi. 199 – 207; Am. Jour. Sci., 1862, (2,) xxxiii. 320 – 327.

Geology of Canada. Montreal, 1863, 983 pp., with atlas.

Kupfererze führende Gesteine am Oberen See. Leonhard's Jahrbuch, 1864, p. 741.

Geology of Canada. Ottawa, 1866, 321 pp. Contains a Report on Lake Superior by Thomas Macfarlane.

Notes on the Report of Mr. Robert Bell on the Nipigon Region. Geol. Surv. of Canada, Rep. of Prog., 1866-69, pp. 471-475.

Logan, William E., *and* T. Sterry Hunt.

A Sketch of the Geology of Canada, in Canada at the Paris Exhibition, 1855, pp. 411-454.

Lyell, Charles.

New York Industrial Exhibition. Sir Charles Lyell's Special Report on the Geological, Topographical, and Hydrographical Departments. Blue Book, 1854, xxxvi., 50 pp. Annales des Mines, 1854, (5,) vi. 1-83.

Macfarlane, James.

Geologist's Travelling Hand-Book. New York, 1878, 261 pp.

Macfarlane, Thomas.

On the Primitive Formations in Norway and in Canada. Canadian Nat. and Geol., 1862, vii. 1-20, 113-128, 161-171.

Report on the Geology of Lake Superior. Geol. of Canada, 1866, pp. 115-164.

On the Rocks and Cupriferous Beds of Portage Lake, Michigan. Canadian Nat. and Geol., 1866-68, (2,) iii. 1-18; Geol. of Canada, 1866, pp. 149-164.

On the Geological Formations of Lake Superior. Canadian Nat. and Geol., 1866-68, (2,) iii. 177-202, 241-257.

On the Geology and Silver Ore of Wood's Location, Thunder Cape, Lake Superior. Canadian Nat. and Geol., 1869, (2,) iv. 37-47, 459-463.

Remarks on Canadian Stratigraphy. Canadian Nat. and Geol., 1879, (2,) ix. 91-102.

Marcou, Jules.

Réponse à la Lettre de MM. Foster et Whitney sur le Lac Supérieur. Bull. Soc. Geol. France, 1850, (2,) viii. 101-105.

A Geological Map of the United States and the British Provinces of North America, with an Explanatory Text, Geological Sections, etc. Boston, June, 1853. 92 pp.

Esquisse d'une Classification des Chaines de Montagnes d'une Partie de l'Amérique du Nord. Comptes Rendus, 1854, xxxix. 1192-1197; Annales des Mines, 1855, (5,) vii. 329-350; Mining Mag., 1856, vii. 321-333.

Résumé explicatif d'une Carte Géologique des États-Unis et des Provinces Anglaises de l'Amérique du Nord, avec un Profil Géologique allant de la Vallée du Mississipi aux Côtes du Pacifique, et une Planche de Fossiles. Bull. Soc. Geol. France, 1854-55, (2,) xii. 813-936.

Die Geologie der Vereinigten Staaten und der Englischen Provinzen von Nord-Amerika von Jules Marcou. Petermann's Geographische Mittheilungen, 1855, pp. 149 – 159.

Geology of North America, with Three Geological Maps and Seven Plates of Fossils. Zurich, 1858, 144 pp.

Reply to the Criticisms of James D. Dana. Zurich, 1859, 40 pp.

Dyas et Trias ou le Nouveau Grès Rouge en Europe dans l'Amérique du Nord et dans l'Inde. Zurich, 1859, 63 pp.

On the Primordial Fauna and the Taconic System. Proc. Bost. Soc. Nat. Hist., 1860, vii. 369 - 382.

Marteaux en pierre des anciens Américains, pour l'Exploitation des Mines de Cuivre et d'Argent Natifs du Lac Supérieur. Comptes Rendus, 1866, lxii. 470, 471.

Marvine, A. R.

Geology of Michigan, Part II., 1873.

See T. B. Brooks.

Mather, W. W.

Notes and Remarks connected with Meteorology on Lake Superior, etc. Am. Jour. Sci., 1848, (2,) vi. 1 – 20.

McCracken, S. B.

The State of Michigan, embracing Sketches of its History, Position, Resources, and Industries. Lansing, 1876, pp. 48 - 69.

M'Kellar, Peter.

* Mining on the North Shore of Lake Superior. Toronto, 1874, 26 pp.

McKenney, Thomas L.

Sketches of a Tour to the Lakes. Baltimore, 1827, 493 pp. North American Review, 1827, xxv. 334 – 352.

McNair, D. K.

See Charles T. Jackson.

Mitchell, Samuel L.

Native Copper of North America. Medical Repository, 1818, (2,) iv. 101, 102.

Mosler, Chr.

Der Kupferbergbau am Obern See in Nordamerika. Zeitschr. Berg. Hütt. Salin., 1877, Abhandlungen, xxv. 203 – 221; 1879, xxvii. 77 – 97.

Müller, Alb.

Ueber die Kupferminen am Obern See im Staate Michigan, Nordamerika. Verhandlungen der Naturforschenden Gesellschaft in Basel. 1857, pp. 411 – 438; Leonhard's Jahrbuch, 1857, pp. 79 – 82, 589, 590.

Murchison, Roderick I.

Siluria. London, 1854, 523 pp.

Murray, Alexander.

North Shore of Lake Superior. Geol. Surv. of Canada, 1846 – 47, pp. 47 – 57.

* Geology of Western Canada. Canadian Jour., 1854-55, (1,) iii. 27-29, 48-52, 73-76.

Murrish, John.

Report on the Geological Survey of the Mineral Regions. Trans. Wisc. Agr. Soc., 1872-73, pp. 469-494.

Newberry, J. S.

Notes on the Surface Geology of the Basin of the Great Lakes. Proc. Bost. Soc. Nat. Hist., 1862, ix. 42-46.

On the Surface Geology of the Basin of the Great Lakes and the Valley of the Mississippi. Ann. of the Lyc. of Nat. Hist., 1870, ix. 213-234.

The Iron Resources of the United States. International Review, 1874, ii. 754-780.

Nicholson, H. Alleyne.

On the Geology of the Thunder Bay and Shabendowan Mining Districts on the North Shore of Lake Superior. Quart. Jour. Geol. Soc., 1873, xxix. 17-24.

On the Mining District on the North Shore of Lake Superior. Trans. of North of England Inst. of Min. and Mech. Eng. Newcastle-on-Tyne, 1874-75, xxiv. 237-249, with maps.

Nöggerath, Johann Jacob.

Von dem Gediegen-Kupfer mit Gediegen-Silber am den Gruben von *Kewena Point.* Leonhard's Jahrbuch, 1848, p. 555.

Owen, David D.

Preliminary Report on the Geological Survey of Wisconsin and Iowa. Senate Docs., 1st Sess. 30th Cong., 1847-48, ii., No. 2, pp. 160-174.

Lake Superior. Report of a Geological Reconnoissance of the Chippewa Land District of Wisconsin, etc. Senate Docs., 1st Sess. 30th Cong., 1847-48, vii., No. 57, 134 pp. Am. Jour. Sci., 1850, (2,) x. 1-12.

Abstract of an Introduction to the Final Report of the Geological Surveys made in Wisconsin, Iowa, and Minnesota in the Years 1847, '48, '49, and '50, containing a Synopsis of the Geological Features of the Country. Proc. Am. Assoc. Adv. Sci., 1851, v. 119-132.

Report of a Geological Survey of Wisconsin, Iowa, and Minnesota. Am. Jour. Sci., (2,) 1853, xv. 296-299; Philadelphia, 1852, 638 pp., with maps. Am. Jour. Sci., 1853, xv. 296-299.

Catalogue of Geological Specimens collected by David D. Owen. Smithsonian Report, 1854, pp. 393-396.

Description of two new Minerals and a new Earth. Jour. Acad. Nat. Sci. Phil., 1852, (2,) ii. 179-183; Am. Jour. Sci., 1852, (2,) xiii. 420-423; Ann. Sci. Discov., 1853, pp. 290, 291.

Palliser, John, *and* **James Hector.**

Papers relative to the Exploration of British North America. Blue Book, 1859, Sess. 2, xxii., 64 pp., with maps.

Peckham, S. F., *and* **C. W. Hall.**

Lintonite and other Forms of Thomsonite. Am. Jour. Sci., 1880, (3,) xix. 122-130.

Perry, John B.

See Charles T. Jackson.

Phillips, J. V.

The Geology of the Upper Mississippi Lead Region. Mining Mag., New York, 1854, ii. 129 – 138.

Piggot, A. Snowden.

On Copper and Copper Mining. Philadelphia, 1858, 388 pp.; Mining Mag., 1858, x. 124–142, entitled History of the Copper Region of Lake Superior.

Porter, George F.

Report on the Copper Rock. George F. Porter in Thomas L. McKenney's Tour to the Lakes, Baltimore, 1827, pp. 477, 478.

Posselt, C.

Die Kupfer-Distrikte des Obersee's, Lake Superior. Leonhard's Jahrbuch, 1856, pp. 1 – 10.

Preston, Samuel.

Copper Ore on Lake Superior. Niles's Weekly Register, 1829, (3,) xii. 203.

Pumpelly, Raphael.

The Paragenesis and Derivation of Copper and its Associates on Lake Superior. Am. Jour. Sci., 1872, (3,) iii. 188 – 198, 243 – 258, 347 – 353; Leonhard's Jahrbuch, 1872, pp. 538 – 540; Geol. of Michigan, Part II., 1873.

On Pseudomorphs of Chlorite after Garnet at Spurr Mountain Iron Mine. Am. Jour. Sci., 1875, (3,) x. 17 – 21.

Metasomatic Development of the Copper-bearing Rocks of Lake Superior. Proc. Am. Acad., 1878, xiii. 253 –309.

See T. B. Brooks *and* T. C. Chamberlain.

Rath, Gustav vom.

Ueber Kalkspath vom Oberen See. Pogg. Ann., 1867, cxxxii. 387 – 404; Leonhard's Jahrbuch, 1868, pp. 347, 348.

Rawson, A. L.

Pictured Rocks of Lake Superior. Harper's New Monthly Mag., 1867, xxxiv. 681.

Relfe, James H.

Sale of Mineral Lands. Reports of Committees, 1845 – 46, 1st Sess. 29th Cong., iii., No. 591, 51 pp. with map. Contains part of Douglass Houghton's Fourth Report, and some Analyses by Charles T. Jackson.

Richardson, John.

On some Points of the Physical Geography of North America in Connection with its Geological Structure. Quart. Jour. Geol. Soc., 1851, vii. 212 – 215.

Rivot, L. E.

Mémoire sur le Gisement du Cuivre Natif au Lac Supérieur. Comptes Rendus, 1855, xl. 1306 –1309.

Voyage au Lac Supérieur. Annales des Mines, 1855, (5,) vii. 173 – 328;

Mining Mag., 1856, (1,) vi. 28 – 37, 99 – 106, 207 – 213, 414 – 418; vii. 249 – 255, 359 – 367; 1857, ix. 60 – 65.

Notice sur le Lac Supérieur. Annales des Mines, 1856, (5,) x. 365 – 474.

Über die Kupfererz-Lagerstätten am Obersee in den Nordamerikanischen Freistaaten. Berg. u. Hütten. Zeit., 1856, pp. 261 – 263, 269 – 271, 293 – 295, 277 – 279, 314, 315, 317, 318, 325 – 328, 333, 334, 341 – 343, 349 – 351, 357 – 359, 365 – 367, 381, 382.

Analysis of Lake Superior Iron Ore. Mining Mag., 1856, vii. 301.

Rogers, H. D.

Mineralogy and Geology of Lake Superior. Proc. Bost. Soc. Nat. Hist., 1846, ii. 124, 125.

Rogers, William B.

On the Origin of the Actual Outlines of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1848, i. 79, 80.

Age of the Sandstone. Proc. Bost. Soc. Nat. Hist., 1860, vii. 394, 395.

Rolker, Charles M.

The Allouez Mine and Ore Dressing, as practised in the Lake Superior Copper District. Trans. Am. Inst. Min. Eng., 1877, v. 584 – 606.

Rominger, Charles.

Observations on the Ontonagon Silver Mining District and the Slate Quarries of Huron Bay. Geol. Surv. of Michigan, 1876, iii. 153 – 166.

See T. B. Brooks, Geol. Surv. of Michigan, 1873, i., Part III.

Rottermund, Count de.

Report on the Exploration of Lakes Superior and Huron. Canada Legislative Assembly, 1856, 24 pp.; Canadian Jour., 1856, (2,) i. 446 – 452.

Ruggles, D.

Tides in the North American Lakes. Am. Jour. Sci., 1843, (1,) xlv. 18 – 27.

Considerations respecting the Copper Mines of Lake Superior. Am. Jour. Sci., 1845, (1,) xlix. 64 – 72.

Russell, John L.

Wood from the Terraces of Lake Superior. Proc. Bost. Soc. Nat. Hist., 1850, iii. 273.

Sanders, George N.

Mineral Lands of Lake Superior. Senate Docs., 2d Sess. 28th Cong., 1844 – 45, vii., No. 117, pp. 3 – 9; xi., No. 175, pp. 8 – 14.

See John Stockton.

Sauvage, E.

Notice sur les Minerais de Fer du Lac Supérieur. Annales des Mines, 1875, (7,) viii. 1 – 35.

Schoolcraft, Henry R.

Narrative Journal of Travels through the Northwestern Regions of the United States, extending from Detroit through the Great Chain of American Lakes to the Sources of the Mississippi River. Albany, 1821, 419 pp. with map.

Account of the Native Copper on the Southern Shore of Lake Superior, with Historical Citations and Miscellaneous Remarks, in a Report to the Department of War. 1821. Am. Jour. Sci., 1821, (1,) iii. 201 – 216; Quart. Jour. Sci., 1822, xii. 422 – 423.

On the Number, Value, and Position of the Copper Mines on the Southern Shore of Lake Superior. Senate Papers, 2d Sess. 17th Cong., 1822, Doc. 5, 33 pp.

Notice of a Recently Discovered Copper Mine on Lake Superior, with several other Localities of Minerals. Am. Jour. Sci., 1824, (1,) vii. 43 – 49.

Narrative of an Expedition through the Upper Mississippi to Itasca Lake, the Actual Source of this River. New York, 1834, 307 pp. with map. Contains a Report by Douglass Houghton.

Localities of Minerals observed in the Northwest in 1831 and 1832. Discovery of the Source of the Mississippi, pp. 157 – 159. New York, 1834.

On the Production of Sand Storms and Lacustrine Beds by Causes associated with the North American Lakes. Proc. Brit. Assoc. Adv. Sci., 1842, xii. Trans. Sections, 42 – 44; Am. Jour. Sci., 1843, (1,) xliv. 368 – 370.

A Memoir on the History and Physical Geography of Minnesota. Minn. Hist. Coll., 1850 – 56, i. 108 – 132.

Summary Narrative of an Exploratory Expedition to the Sources of the Mississippi River in 1820, resumed and completed by the Discovery of its Origin in Itasca Lake in 1832. Philadelphia, 1854. Purports to contain many of the original Reports to the War Department, and other papers.

Selwyn, Alfred R. C.

Notes of a Geological Reconnoissance from Lake Superior to Fort Garry. Geol. Surv. of Canada, Rep. of Prog., Montreal, 1872 – 73, pp. 8 – 18.

The Stratigraphy of the Quebec Group and the Older Crystalline Rocks of Canada. Canadian Nat. and Geol., 1879, (2,) ix. 17 – 32; Geol. Surv. of Canada, Rep. of Prog., 1877 – 78, A. 15 pp.

Shepard, Charles U.

On the Copper and Silver of Kewenaw Point, Lake Superior. Proc. of the Sixth Ann. Meet. of the Assoc. of Am. Geol. and Nat., New Haven, 1845, 60, 61.

Tautolite on the North Shore of Lake Superior. Am. Jour. Sci., 1847, (2,) iv. 278.

Shepherd, Forrest.

Remarks on a Boulder Mass of Native Copper from the Southern Shore of Lake Superior. Am. Jour. Sci., 1847, (2,) iv. 115, 116.

Observations on the Drift, Furrows, Grooves, Scratches, and Polished Surfaces of the Rocks of Lake Superior. Am. Jour. Sci., 1847, (2,) iv. 282, 283.

Spencer, Joseph William.

Lake Superior. — On the Nipigon or Copper-bearing Rocks of Lake Superior, with Notes on Copper Mining in that Region. Canadian Nat. and Geol., 1878, (2,) viii. 55 – 81.

Stanard, B. A.

Stanard's Rock. In the "Mineral Regions of Lake Superior," by J. Houghton, Jr., and T. W. Bristol, page 81.

Stevens, William H.

The Prospects of the Lake Superior Mining Region. Mining Mag., 1854, ii. 149 – 153.

Stockton, John.

Report on the Mineral Lands of Lake Superior. Senate Docs., 1844 – 45, 2d Sess. 28th Cong., xi., No. 175, 22 pp. with map. Contains reports by Messrs. J. B. Campbell, George N. Sanders, and A. B. Gray.

Strong, Moses.

See T. C. Chamberlain.

Sweet, E. T.

Notes on the Geology of Northern Wisconsin. Trans. Wisc. Acad., 1875 – 76, iii. 40 – 55.

See T. C. Chamberlain.

Swineford, A. P.

History and Review of the Copper, Iron, Silver, Slate, and other Material Interests of the South Shore of Lake Superior. Marquette, Mich., 1876. Contains Ancient Copper Miners, J. Houghton, 78 – 89; C. E. Wright, Geology of the Lake Superior Iron District, 132 – 145.

Tamnau, F.

Minerals from the Copper District of Lake Superior. Zeit. Deut. Geol. Gesells., 1852, vi. 3 – 6, 9, 10; 1854, vi. 11; Leonhard's Jahrbuch, 1854, 442, 443; 1855, 349.

Teschemacher, J. E.

Harmotome and Volborthite from Lake Superior. Proc. Bost. Soc. Nat. Hist., 1849, iii. 105, 106.

Tod, David.

See William Bartlit.

Tuttle, H. B.

See T. B. Brooks.

Verneuil, Édouard P. de.

Lettre sur la Géologie des États-Unis. Bull. Soc. Géol. France, 1846 – 47, (2,) iv. 12, 13.

Whiting, Henry.

Remarks on the Supposed Tides and Periodical Rise and Fall of the North American Lakes. Am. Jour. Sci., 1831, (1,) xx. 205 – 219.

Whitney, J. D.

Description and Analysis of Three Minerals from Lake Superior. Bost. Jour. Nat. Hist., 1847, v. 486 – 489; Am. Jour. Sci., 1848, (2,) vi. 269, 270.

Jacksonite, a New Mineral from the Lake Superior Region. Proc. Bost. Soc. Nat. Hist., 1848, iii. 5, 6.

Chlorastrolite, from Isle Royale, Lake Superior. Proc. Bost. Soc. Nat. Hist., 1848, iii. 12.

Chemical Examination of some American Minerals. Bost. Jour. Nat. Hist., 1850 – 57, vi. 36 – 42; Proc. Bost. Soc. Nat. Hist., 1848, iii. 78, 79; Am. Jour. Sci., 1849, (2,) vii. 434, 435.

Black Oxide of Copper at Copper Harbor, Lake Superior. Proc. Bost. Soc. Nat. Hist., 1849, iii. 102, 103; Ann. Sci. Discov., 1850, pp. 261, 262; Am. Jour. Sci., 1849, (2,) viii. 273, 274.

The Lake Superior Copper and Iron District. Proc. Bost. Soc. Nat. Hist., 1849, iii. 210 – 212.

Fracture of Slate at the Jackson Forge. Proc. Bost. Soc. Nat. Hist., 1850, iii. 226.

Catalogue of the Rocks, Minerals, etc., collected on the District between Portage and Montreal River, during the Years 1847 and 1848, by J. D. Whitney. Smithsonian Report, 1854, pp. 387 – 392.

The Metallic Wealth of the United States. Philadelphia, 1854, 510 pp.

Review of Murchison's Siluria. Am. Jour. Sci., 1855, (2,) xix. 371 – 385.

Remarks on some Points connected with the Geology of the North Shore of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1855, ix. 204 – 209.

On the Occurrence of the Ores of Iron in the Azoic System. Proc. Am. Assoc. Adv. Sci., 1855, ix. 209 – 216; Mining Mag., 1856, vii. 67 – 73; Am. Jour. Sci., (2,) 1856, xxii. 38 – 44.

Notice of New Localities, and Interesting Varieties of Minerals, in the Lake Superior Region, supplementary to the Chapter on this subject in Part II. of the Report of Foster and Whitney. Am. Jour. Sci., 1859, (2,) xxviii. 8 – 20; Mining Mag., 1860, (2,) i. 32 – 47.

Note on the Geological Position of the Lake Superior Sandstone. Mining Mag., 1860, (2,) i. 435 – 446.

On the Chemical Composition of Pectolite. Am. Jour. Sci., 1860, (2,) xxix. 205 – 208.

See Edward Desor, Foster *and* Whitney, *and* Charles T. Jackson.

Whitney, William D.

See Foster *and* Whitney.

Whittlesey, Charles.

On the "Superficial Deposits" of the Northwestern Part of the United States. Proc. Am. Assoc. Adv. Sci., 1851, v. 54 – 59.

On the Ancient Mining Operations on Lake Superior. Proc. Am. Assoc. Adv. Sci., 1857, xi. 42 – 44.

Fluctuations of Level in the North American Lakes. Proc. Am. Assoc. Adv. Sci., 1857, xi. 154 – 160.

On the Origin of the Azoic Rocks of Michigan and Wisconsin. Proc. Am. Assoc. Adv. Sci., 1859, xiii. 301 – 308.

On Fluctuations of Level in the North American Lakes. Smithsonian Contributions to Knowledge, 1859, xii., No. 2, 25 pp.

The Penokie Mineral Range, Wisconsin. Proc. Bost. Soc. Nat. Hist., 1863, ix. 235 – 244.

On the Movements of the Glacial Era in the Valley of the St. Lawrence. Proc. Am. Assoc. Adv. Sci., 1866, xv. 43 – 54.

On the Fresh-Water Glacial Drift of the Northwestern States. Smithsonian Contributions to Knowledge, 1866, xv. 1 – 32; Smithsonian Report, 1866, 32 – 36.

Abstract of Remarks upon the Occurrence of Iron in Masses. Proc. Am. Assoc. Adv. Sci., 1867, xvi. 97 – 107.

On the Cause of the Transient Fluctuations of Level in Lake Superior. Proc. Am. Assoc. Adv. Sci., 1873, xxii., Part II., 42 – 46.

Sudden Fluctuations of Level in Quiet Waters. Records of Observations. Proc. Am. Assoc. Adv. Sci., 1874, xxiii. 139 – 143.

Physical Geology of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1875, xxiv. 60 – 72.

On the Origin of Mineral Veins. Proc. Am. Assoc. Adv. Sci., 1876, xxv. 213 – 216.

See T. C. Chamberlain, *and* Foster *and* Whitney.

Wichmann, Arthur.

A Microscopical Study of some Huronian Clay Slates. Quart. Jour. Geol. Soc., 1879, xxxv. 156 – 164.

See T. C. Chamberlain.

Wight, O. W.

See T. C. Chamberlain.

Williams, C. P., *and* J. F. Blandy.

Some Contributions to a Knowledge of the Constitution of the Copper Range of Lake Superior. Am. Jour. Sci., 1862, (2,) xxxiv. 112 – 120.

Wilson, Daniel.

The Ancient Miners of Lake Superior. Canadian Journal, 1856, (2,) i. 225 – 237.

The Southern Shores of Lake Superior. Canadian Journal, 1856, (2,) i. 344 – 356.

Winchell, Alexander.

First Biennial Report of the Progress of the Geological Survey of Michigan. Lansing, 1861, 339 pp.

Notice of a small Collection of Fossils from the Potsdam Sandstone of Wisconsin and the Lake Superior Sandstone of Michigan. Am. Jour. Sci., 1864, (2,) xxxvii. 226 – 232.

* Geological Map of Michigan. Philadelphia, 1866. Leonhard's Jahrbuch, 1868, pp. 99 – 101.

The Isothermals of the Lake Region. Proc. Am. Assoc. Adv. Sci., 1870, xix. 106 – 117.

The Diagonal System in the Physical Features of Michigan. Am. Jour. Sci., 1873, (3,) vi. 36 – 40.

Winchell, N. H.

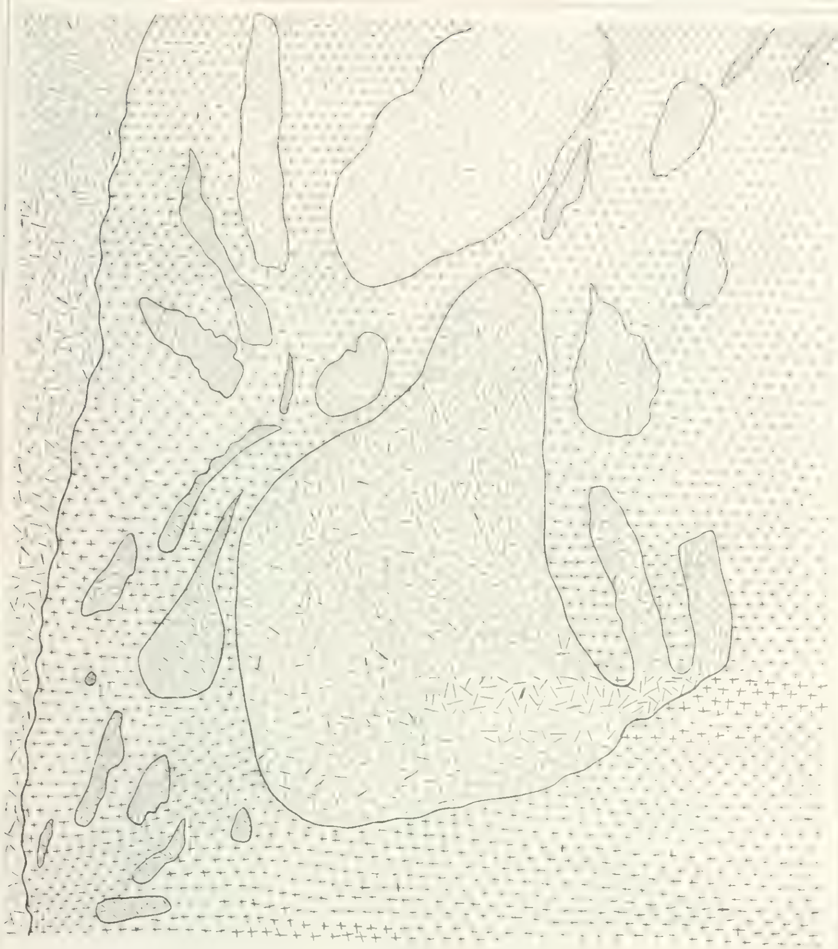
The Glacial Features of Green Bay of Lake Michigan, with some Observations on a Former Outlet of Lake Superior. Am. Jour. Sci., 1871, (3,) ii. 15 – 20.

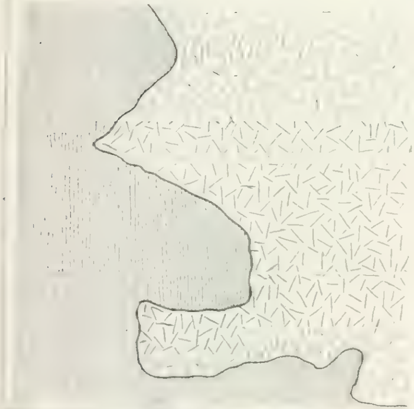
The Geological and Natural History Survey of Minnesota. 1872 – 1878. 7 volumes. Geology of Lake Superior, 1st, 2d, and 7th vols. The last contains a Report by C. W. Hall.

Wright, Charles E.

First Annual Report of the Commissioner of Mineral Statistics of the State of Michigan for 1877 – 78. Marquette, 1879, 229 pp.

See T. B. Brooks, T. C. Chamberlain, *and* A. P. Swineford.





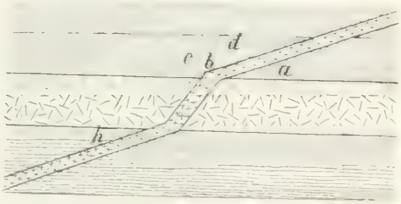


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PLATE VI.

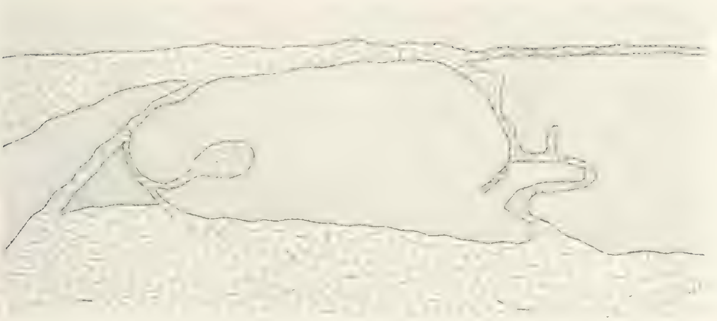
FIGURE 25. (page 51) shows in section the relation of the "soft hematite," represented by oval marks, to the jasper and ore above and on both sides of it; also to fissures which allow the percolation of water, the upper portion of the figure being adjacent to the surface of the ground. McComber Mine, Negaunee.

FIGURE 26 (page 55) shows in section reddish eruptive granite cutting gray gneiss. The granite at the left and bottom of the figure is connected with the main body of the granite. South of Ishpeming.

FIGURE 27 (page 113) represents in section a tongue of trap extending down into the ash-bed, and holding a rounded fragment of the latter. End of drift, Sept. 12, 1879, 5th level. Copper Falls Mine, Keweenaw Point.

FIGURE 28 (page 113) shows the denuded and irregular surface of the underlying sandstone, covered by the overlying lava flow. Emerson Adit, Copper Falls Mine, Keweenaw Point.

All the figures, except when otherwise stated, are from free-hand sketches made in the field from actual observed occurrences. No attempt has been made to draw to scale, or to show anything except the actual relations of the rocks to one another. The sketches were redrawn by the writer, engraved on stone by Mr. L. Trouvelot, and printed by A. Meisel.



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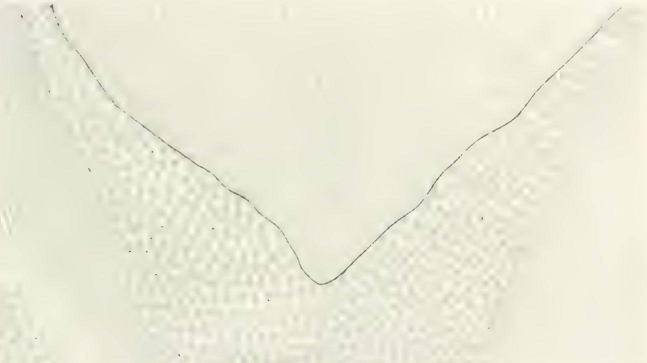

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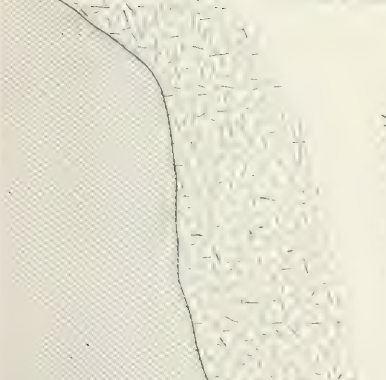

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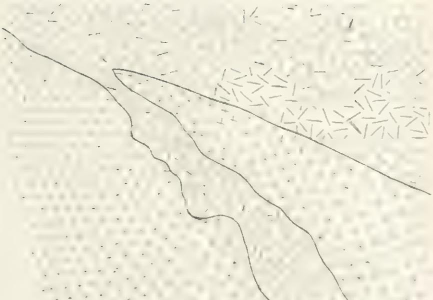

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PLATE I.

FIGURE 1 (page 30) represents the contact of the jasper and ore on the left hand with the schist on the right. This section shows the relations of the banding of the jasper to the line of junction. Lake Superior Mine, Ishpeming.

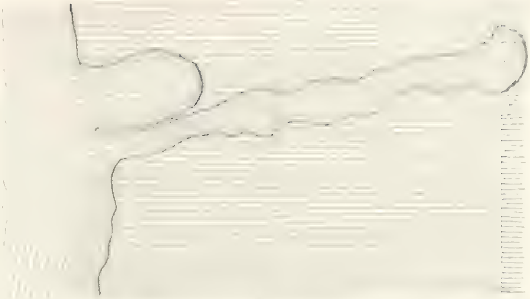
FIGURE 2 (page 30) represents in plan the projection of the banded jasper on the left into the schist on the right, the banding running parallel to the walls. Lake Superior Mine, Ishpeming.

FIGURE 3 (page 30) represents in section a dike of very fair hematite ore, extending across the lamination of the schist. Lake Superior Mine, Ishpeming.

FIGURE 4 (page 31) is a section showing the relations of the branching dikes of hematite to the schist. Cleveland Mine, Ishpeming.

FIGURE 5 (page 31) shows in section the relation of the jasper and ore to the underlying schist. Jackson Mine, Negaunee.

FIGURE 6 (page 31) shows in section the relations of the hematite to the schist. The hematite projects in a large knob-like mass up into the schist, and is connected with the main body of ore below. Jackson Mine, Negaunee.



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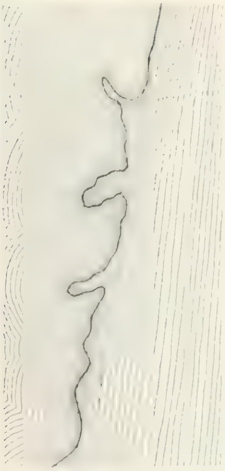

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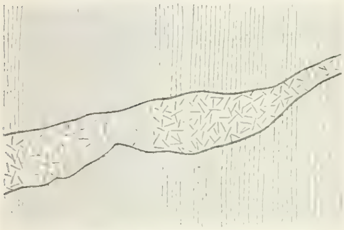

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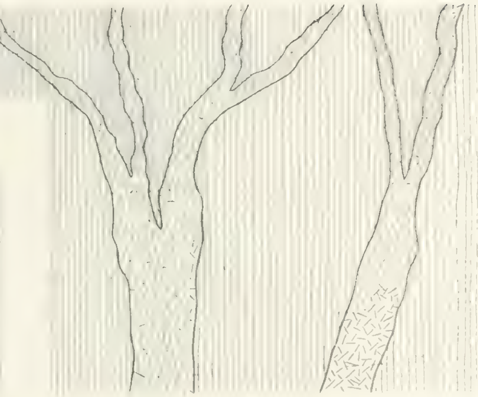

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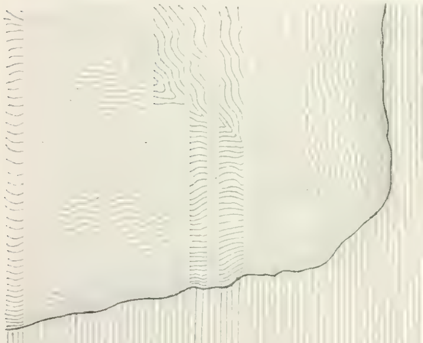

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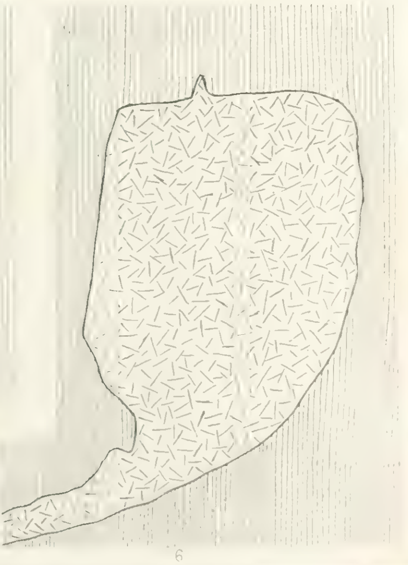

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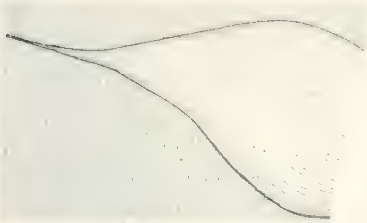
PLATE II.

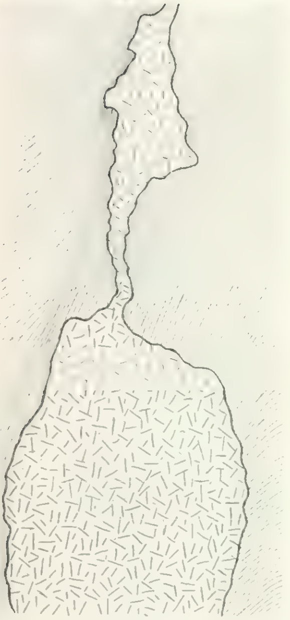
Figure 7 (page 31) represents a section of a dike of iron ore extending across the lamination of the schist. Jackson Mine, Negaunee.

Figure 8 (pages 31, 32) represents in section the relations of a decomposed hematite ("soft hematite") to the schist. In this case the curvature and dislocation of the schist by the upthrust of the ore is well shown, as represented along the curve *b*, *c*. Of our own knowledge we cannot state that the part *a* belongs to the hematite on the right, as represented. Jackson Mine, Negaunee.

Figure 9 (page 32) shows a section of jasper and ore intruding in a wedge-shaped mass obliquely through the schist. Jackson Mine, Negaunee.

Figure 11 (page 32) represents in section the intrusion of ore in a dike of varying dimensions between and across the laminæ of the schist, bending them in different directions, as shown to a certain extent in the figure. Jackson Mine, Negaunee.





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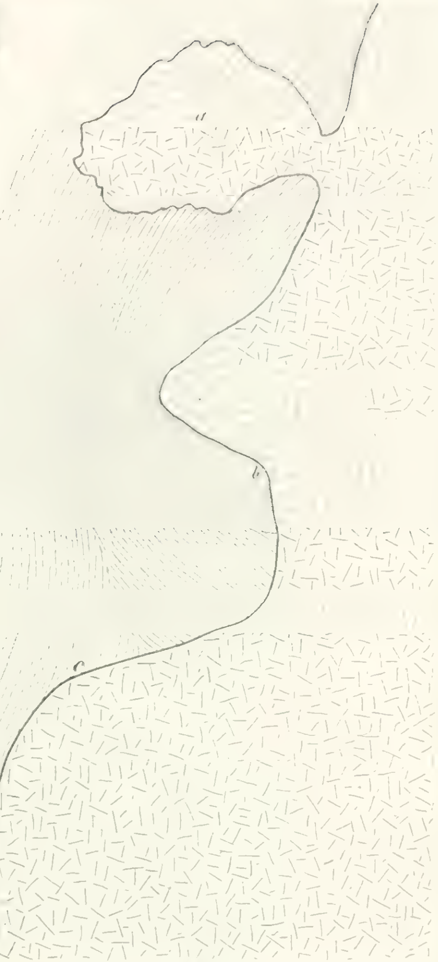


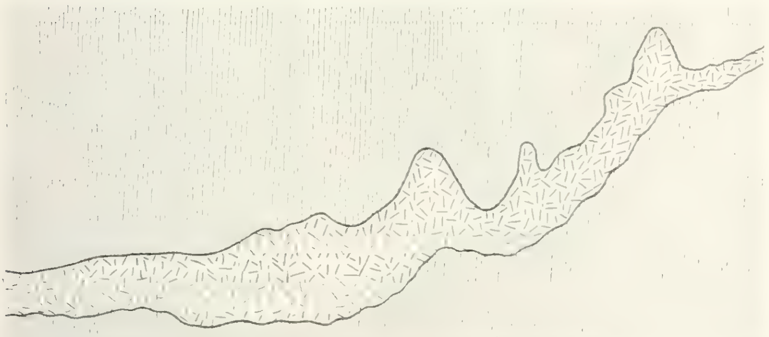
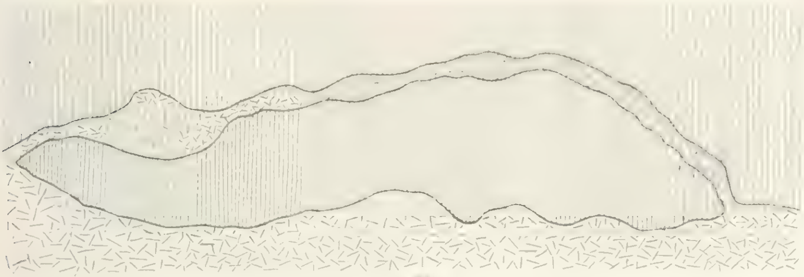


PLATE III.

FIGURE 10 (page 32) represents in section the ore passing around and cutting off a portion of the schist, some six feet in length, from the main body. The ore at the lower portion of the figure was then being mined, the schist forming a *horse* in it. Jackson Mine, Negaunee.

FIGURE 12 (page 32) shows the relations of ore, which was then being mined, to its overlying schist. This represents a section some twenty feet in length. Jackson Mine, Negaunee.

FIGURE 13 (page 32) represents a section of a jasper dike in a sandstone. The dike is of irregular width, and approximately follows the stratification of the sandstone in its main course. It sends projections in places out across the laminæ, breaking, contorting, and indurating them. The dike is some fifteen feet in length, and in the figure its width has been greatly exaggerated compared with its length. Home Mine, Cascade Range.



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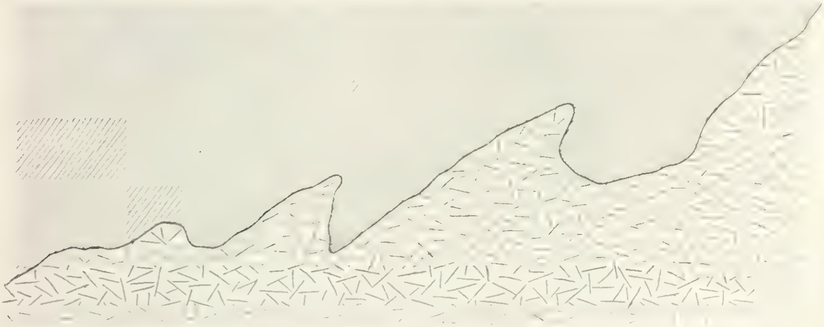

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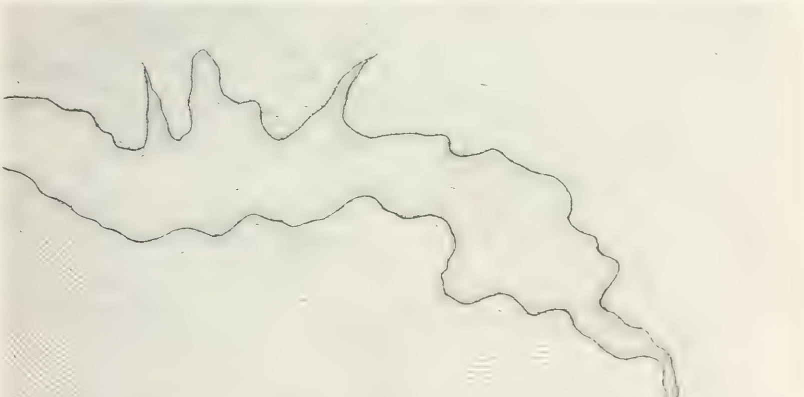


PLATE IV.

Figure 14 (page 36) represents in plan a "diorite" dike with a tongue extended into the schist. Light-house Point, Marquette.

Figure 15 (page 36) shows in plan the line of junction of a "diorite" with the schist. Quarry near Light-house, Marquette.

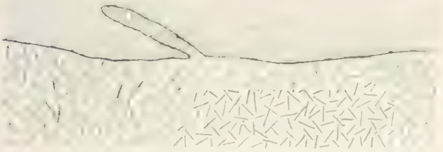
Figure 16 (pages 36, 38) shows in plan the relations of a felsite, represented on the right of the figure by angular marks, to a later "diorite" dike and to the schist. The "diorite" cuts and faults the felsite, but as the portion to the left of the "diorite" is under the waters of the lake, the writer is not sure of the accuracy of that portion of the figure.

Figure 18 (page 41) shows in plan the line of junction between the "diorite" and schist. East of Ishpeming.

Figure 19 (page 41) shows in plan the line of contact between the "diorite" and schist, with an enclosed fragment of schist in the "diorite." Northeast of the Cleveland Mine, Ishpeming.

Figure 20 (page 41) is a section, chiefly ideal, showing the supposed relations of the "diorite" dike to the adjacent schist, at the same locality as Fig. 19.

Figure 21 (page 41) represents in plan the line of junction between the "diorite" and schist. Northeast of the Cleveland Mine, Ishpeming.



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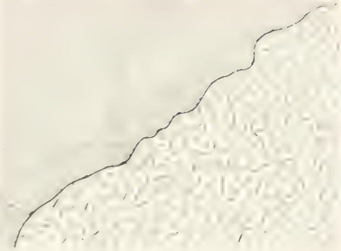

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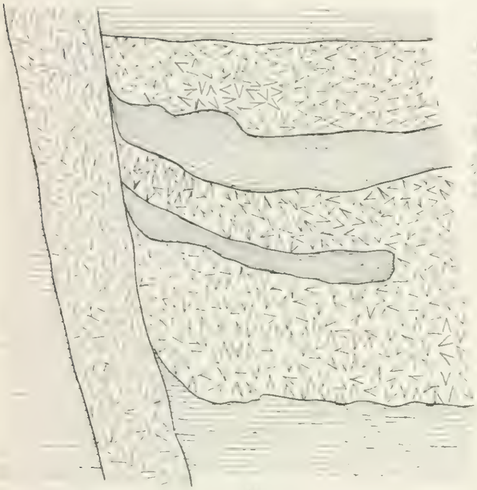

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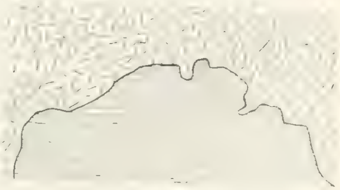

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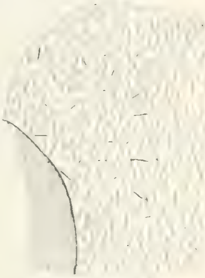

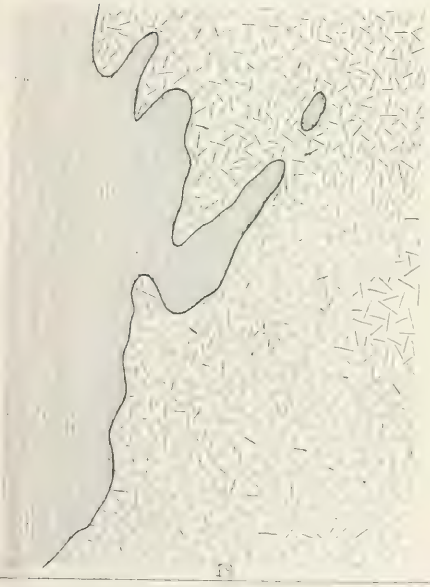

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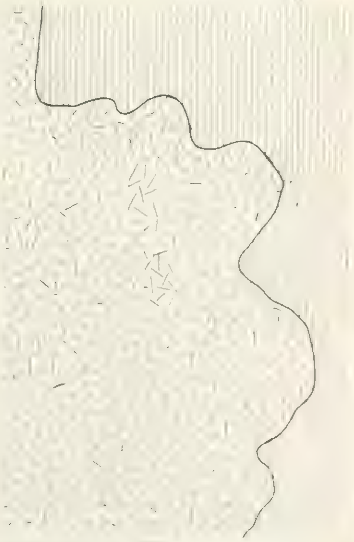

PLATE V.

FIGURE 17 (page 39) shows in plan the relations of the granite denoted by the crossed (+) space to the "diorite." The "diorite" shows in mass on the left, and in rounded fragments in the granite. Picnic Point, north of Marquette.

FIGURE 22 (page 41) represents the line of junction between the "diorite" on the right with the schist on the left. Northeast of the Cleveland Mine, Ishpeming.

FIGURE 23 (pages 49, 50) represents a plan, partly ideal, of a narrow diabase dike cutting a broad "diorite" dike and the schists at Ishpeming. The lettering is explained in the text. Salisbury Mine, Ishpeming.

FIGURE 24 (pages 49, 50) is an ideal section showing the supposed relation of the above "diorite" to the schists. Salisbury Mine, Ishpeming.

No. 2. — *The Felsites and their Associated Rocks North of Boston.*

By J. S. Diller.

The extremely interesting and complicated petrology of Eastern Massachusetts has been the subject of a great deal of discussion, and at no time in the past have opinions concerning the origin and relations of the rocks been more at variance than at present. It is important, therefore, that the facts to be found in nature be carefully observed and described in order that the various differences of opinion may, as far as possible, be removed and the truth demonstrated. There are, however, certain localities whose facts appear, under the eyes of some observers, to be very different from those seen by other observers in the same place; and it seems necessary in such cases, where the facts are questioned, to describe them with more than usual detail.

The field we have explored includes Melrose, Malden, and the southern portions of Medford, Stoneham, Wakefield, Saugus, and Lynn. Within this area felsite is the chief rock, and with it are associated, besides a complex group of tufaceous rocks, commonly called breccias, a group of stratified rocks, granites, diorites, slates, and diabases. The recent "Contributions to the Geology of Eastern Massachusetts," by W. O. Crosby, contains a map upon which the general distribution of the rocks, so far as we know, is quite correctly given; but, as Mr. Crosby is doubtless well aware, there are many places, and some of them important, too, where the map is in error. We cannot expect to have for many years to come a very accurately detailed geological map of this neighborhood, for even if we had, what we have not, a correct topographical map to use as a basis of geological work, the extreme complexity of the rocks, together with their highly altered condition and the existence of quite extensive covered areas must necessarily require a long time for correct delineation. In determining the relative age of eruptive rocks we have been guided by the generally accepted criterion, viz. that of two rocks, the one which penetrates the other in dike-like masses or contains fragments of the other is the younger. In considering the rocks associated with the felsites, we shall notice them in the order of their ages, beginning with the oldest, and endeavor to describe the facts apart from theoretical considerations.

Stratified Group.

The name *stratified group* is applied to certain rocks whose only common character is that of stratification; and although the rocks of the Boston basin, and also some of the so-called breccias, are distinctly stratified, there is no difficulty in separating the first group, at least geographically, from the others, for its distribution is widely different. The stratified group, consisting chiefly of quartzite and argillaceous rocks, forms an important area, extending from Medford northeast across Spot Pond and Melrose into Saugus. It is a long, narrow band, and fortunately it adjoins the granite, felsite and diorite, so that we have upon the borders of this area the means of determining the relations of all of the rocks mentioned. The petrological relations of this group and its probable much wider distribution upon the surface in former times will be considered later.

Granite.

The granite occupies a large area in Medford southwest of Spot Pond, and also in the eastern part of Melrose, extending into central and northern Saugus. In Malden there are four small areas of granite, one near Pleasant Street between Malden and Medford, another northeast of Prospect Hill, a third along the Newburyport turnpike north of Broadway station, and a fourth near Franklin Park.

The relation of the granite to the stratified group is shown by many facts so evident, that, as far as the phenomena themselves are concerned, there is no difference of opinion among observers.

North of Howard Street, along the Melrose-Saugus line, and at other places, the granite occurs in oblong or irregular patches, apparently as an eruptive in the stratified group. The facts in these cases are, however, not as convincing as others so abundant throughout the regions in which the granites predominate. It has been frequently observed that upon Marblehead Neck the coarsely crystalline granite contains fragments of distinctly stratified rocks. In the granite of Medford stratified fragments are abundant, and sometimes at a considerable distance from the nearest large outcrops of their parent rock. This is especially the case with those found near the western base of Pine Hill. The granite in a beautifully glaciated exposure near the west end of Long Pond, Melrose, envelops several angular pieces of rock in which the stratification can be readily traced. Similar phenomena may be observed upon the western shore of Pranker's Pond, Saugus, and Wenunchus Lake, Lynn. A very fine example of stratified inclusions within the granite has been pointed out by Mr. Crosby * at Break-heart Hill, Saugus. The best exposures at this locality are not far from Forest Street, on the west side of a private road leading from Mr. Artemus Edmond's northward towards Pleasant Lake. The coarse-grained granite makes very clearly defined contacts with the stratified rocks which it envelops, and the fragments in which the stratification is prominent are large and numerous, and the facts so evident that they cannot be questioned. It is interesting to notice that the strike and dip of the planes of stratification are about the same in all of the enveloped fragments (strike N. 5° – 10° E. Dip 90°). This phenomenon is developed in a very remarkable degree about half-way between Oakland Vale and Long Pond, where the granite is full of elongated fragments whose stratification is nearly vertical, and whose strike is approximately N. 40° E. This direction corresponds very nearly to a sort of gneissoid arrangement of the minerals in the coarse granite of adjacent localities where the fragments do not occur. Almost all the varieties of rocks which occur in the stratified group are represented by fragments in the granite. The fragments vary in size from an inch to many feet in length, and are generally more highly metamorphosed than the large mass of the group from which they were derived. The quartzite, although occurring in very well marked fragments, is not nearly so abundant as the less silicious varieties.

It is probable that the position of the fragments, in some cases at least, as well as the gneissoid structure found in the same region may indicate the direction of motion in the enveloping mass at the time of its extrusion. The general distribution of the fragments of the stratified group, throughout a greater portion of the granites we have examined, forces us to admit, either that the granites have moved quite a long distance from the present outcropping stratified group, or else that the latter group at the time of the eruption of the granites had a wider distribution. The large dike of diabase at the west base of Pine Hill, Medford, contains quite a number of fragments which closely resemble the quartzite of the stratified group. If they are fragments of quartzite from the stratified group, they must have been brought from beneath the surrounding felsite, either from the stratified group in place, or an included fragment in the granite. Such facts render it probable that before the granites and felsites reached the surface, the stratified group had a much wider distribution than it has at the present time.

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* Contributions to the Geology of Eastern Massachusetts, p. 39.

Felsite.

The felsites, extending from Medford through Malden, Melrose, and Saugus to the eastern part of Lynn, and northward from Melrose into Wakefield, are the prevailing rocks of that region. Their petrological relations have been one of the chief enigmas in the geology of Eastern Massachusetts, and, judging from the present diverse opinions, much thorough work needs to be done before a final solution is reached. Most observers agree that the felsites are of more recent age than the granites; nevertheless, there is a wide difference of opinion concerning the phenomena upon which this common conclusion is based. Some observers maintain that the felsite is younger than the granite, from the fact, as they say, that the felsite not only envelops detached fragments of the granite, but also penetrates it, in the form of distinct dikes. Other observers reach the same conclusion, because, in their opinion, the granite envelops felsitic fragments, and in the form of irregular dikes penetrates the felsite.

It is evident that theoretical considerations are of little value unless supported by facts, and for this reason the latter should be clearly set forth and particularized, apart from theories, so that there may be some hope of securing, ultimately, a uniformity of opinion concerning at least what occurs in the field.

As far as our observations have extended, we have never seen an example of the granite breaking through the felsite or enveloping its fragments. In every case in which we could determine the relations of the rocks the felsite occurred as an eruptive penetrating the granite.

Before proceeding to point out the special localities in which the granite is cut by the felsite, let us consider the evidence, apart from the dikes, which proves the truly igneous nature of the latter rock.

Upon Break-heart Hill in Saugus and to the west towards Main Street there occurs an extremely heterogeneous mixture of banded felsite with grayish fragmental material, which in its external aspect resembles, to a considerable extent, ordinary ashes. The true nature of this grayish rock was not suspected until the microscope revealed the fact that it contains many of the splinter-shaped or chip-like sharp-edged fragments whose peculiar forms belong to the volcanic glass of rhyolitic tufas. The forms are so characteristic, and in this case so well preserved among the other ashy material, that there can be no doubt of their identity. The fragments, as we would expect,* are no longer volcanic glass, but quartz, which is the product of alteration. The composition of this interesting rock, and its petrologic relations, we believe, establish beyond question that it is a veritable ancient volcanic ash. There is considerable evidence, though not yet decisive, for want of further microscopical investigations, that these ashes are distributed in patches throughout a considerable portion of the region occupied by the felsites.

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* On the Classification of Rocks, by M. E. Wadsworth; Bull. Mus. Comp. Zoöl. at Cambridge, Mass., Vol. V., No. 13.

It seems to be certain, therefore, that there has been within this region a true volcanic outburst by which the ashes were produced, and that anterior to the formation of the ashes, or perhaps about the same time, there was an eruption of felsitic lava, with which the ashes became entangled in the complicated manner we find upon Break-heart Hill.

The banding so well marked in the felsites upon the western shore of Marblehead Neck until quite recently has been considered stratification, and therefore appeared to be a fatal argument against the theory of those who regard the felsites as exotic. Dr. Wadsworth was the first to consider the banding a fluidal structure, equivalent to that so prominent in the modern rhyolites, and consequently of igneous origin. It is of common occurrence, especially in the silicious felsites of Lynn, Saugus, and Melrose; and from the fact that where it is found in felsite, forming distinct dikes or tongues in the granite, or enveloping fragments of other rocks, the banding is parallel to the line of contact, there seems to be no good reason for doubting that it was produced by the flowing of the felsitic matter in a state of fusion. The extreme complexity of the banding upon Break-heart Hill and at places in Marblehead Neck cannot be satisfactorily explained by any other supposition, and it is scarcely necessary to add that under the microscope the phenomena of the banding are wholly at variance with those found in sedimentary rocks and completely in harmony with those of altered rhyolites. The banding, therefore, instead of furnishing an argument in favor of the sedimentary origin of the felsites, is proof of their eruptive character.

Since the relation of the felsite and granite has been the subject of such discrepant statements, we shall point out the localities in which, as it seems to us, the relation is clearly exposed. Within the granite southwest of Spot Pond a dike of somewhat pinkish felsite occurs near the top of a high hill west of the north end of Brooks's Lane, where it enters Forest Street. Further northward and nearer to Forest Street there are at least half a dozen smaller dikes of a similar felsite in the granite. That these masses of felsite are true dikes and not included fragments within the granite is proved by the fact that they not only send irregular tongues of felsite from the main dike into the adjoining rock, but also that they hold within themselves detached fragments of the granite which they penetrate. The small patch of granite northeast of Prospect Hill, Malden, is penetrated by one of the largest felsitic dikes of this region. It may be seen in the cliff directly opposite Faulkner's station. Along the Newburyport turnpike in Malden there is a small area of granite to which we have elsewhere * alluded. Mr. Crosby † regards this rock as granitoid petrosilex. We placed it among the granites not only on account of its granitic structure, but from the fact that it is clearly distinct from the adjoining felsite. In a gravel-pit upon the east side of the turnpike, a short distance north from Salem Street, several junctions of the granite and felsite may be seen. The felsite is in some places slightly banded along the contact, and the line of junction between the two rocks can be readily traced from the south part of the gravel-pit for a considerable distance over the hills to the eastward. Passing a short distance northward along the turnpike several low cliffs appear upon the left. In the second of these, two well-marked dikes of reddish felsite occur. One of them is about five feet in width, the other about twelve feet, and they cut through an almost vertical cliff of the granite twenty-five feet in height. These dikes may be traced at intervals for nearly a quarter of a mile to the northeast. The granitic rock of this area, as well as that northeast of Prospect Hill, is quite different in its general aspect from the granite of the larger areas to the northward ; but, so far as the facts are known, there seems to be no good reason for supposing that it is not granite, or that its relation to the felsite is different from that of the other granites.

The large granitic mass extending from eastern Melrose into central and northern Saugus is bounded upon the south and east and partly upon the west by felsite, so we would expect to find within this area numerous exposures of the two rocks in contact, and thereby determine their relations. Near the eastern end of Long Pond in Saugus there are several distinct dikes of felsite in the same granite which at the west end of the pond, about one fourth of a mile distant, as already mentioned, contains well-marked inclusions of the stratified group. One of the most distinctly marked dikes may be found upon the eastern end of the granite hill north of Essex Street, about a quarter of a mile northwest from the Newburyport turnpike. The strike of the dike is N. 20° E., and it varies, within a distance of sixty feet, from six to ten feet in width.

The most interesting and instructive exposures of the stratified group,

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* Proc. Bost. Soc. Nat. Hist., Vol. XX., p. 357.

† Contributions to the Geology of Eastern Massachusetts, p. 78.

granite and felsite near together, are to be found upon Break-heart Hill in Saugus. It is to this locality that Mr. Crosby refers when he says:* "On the high hills to the west of the private road running from Forest Street and Central Brook to Water Street we have, perhaps, the finest example of the extravasation of the granite yet observed in this region. The exposures of the rock here are remarkably good; and the granite is coarse and sharply defined where it penetrates the adjoining petrosilex and hornblende slate in irregular dykes, or envelops isolated masses of these rocks that have been wrested from the parent beds."

Concerning the fact that the granite envelops detached fragments of the stratified group there can be no doubt; but when we come to examine the relations of the felsite and the granite, the evidence is not so easily deciphered. The top of the hill is composed of a mixture of felsite and volcanic ashes, which extends over the southeastern slope, meeting the rocks of the stratified group; to the northward, a short distance, this mixed mass is limited by the coarsely crystalline granite containing the stratified fragments; and to the westward it connects with a large area of similar rocks forming the high hills near by in that direction. Within the small area of this complex rock there are two patches of granite. One of these, with a diameter of about twenty-five feet, upon the western brow of the hill, has its side penetrated by a tongue, at least six feet in length, of very distinctly banded felsite. The banding is also very distinctly marked at several places along the periphery of the granite, and in every case it is parallel to the line of contact between the two rocks. The smaller patch of granite upon the southern slope of the hill is completely enveloped by felsite. Although the felsite in this case is not banded, it apparently sends tongues into the granite, and, near the junction of the two rocks, it envelops small fragments of the larger mass which it surrounds. Although there are other exposed contacts of the felsite and granite in the neighborhood, none were observed to furnish important evidence bearing upon the relations of the two rocks. The banding of the felsite is undoubtedly of igneous origin, and its occurrence about the granite, together with the tongues of felsite penetrating the granite, and fragments of the latter rock enveloped by the former, are phenomena which, as it seems to us, can be explained only by supposing that the felsite flowed through and around the granite.

The well-marked dikes of felsite cutting the granite between Fishing Point and Phillips Beach on the Swampscott coast, as first pointed out by Dr. Wadsworth, as well as the numerous examples found upon the coast of Marblehead Neck, conclude an array of facts which establish, beyond dispute, not only that the felsite is a truly eruptive rock, but also that in every case where we could determine its relation it is younger than the granite which it penetrates.

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* Contributions to the Geology of Eastern Massachusetts, p. 78.

The relation of the felsite to the stratified group is the subject of very different opinions, and for this reason it seems proper to present in detail the evidence we have observed bearing upon this question. If the phenomena described sustain the conclusions already drawn, viz. that the stratified rocks of Medford, Stoneham, Melrose, and Saugus are older than the eruptive granites of that region, and that the felsite is a truly eruptive rock younger than the granites, it is evident that there can be no gradual passage from the felsite into the stratified group.

Mr. Crosby,* who has done so much on the geology of Eastern Massachusetts, refers to the region west of the Boston and Maine Railroad in Melrose as the one which "places beyond question the fact that there is a gradual transition between the quartzite and petrosilex, and that portions of the latter rock are intercalated in the stratified group." This group is well exposed near the railroad, a short distance south of the Melrose station, and extends southwestward, parallel with the general strike of the formation, across Spot Pond into Medford. Excellent outcrops, perhaps the best of the stratified group in this region, form a part of the northern shore of the pond. The felsites and stratified rocks are exposed within several hundred yards of each other upon opposite sides of Washington Street, Melrose, a short distance east of the Melrose-Stoneham line. The exposures in both cases are within the regions marked felsite by Mr. Crosby. Those upon the north side of Washington Street are distinctly sedimentary rocks, while the rocks in the cliffs to the southward are well-marked felsite, slightly porphyritic, of the kind forming the mass of the Malden Highlands. Although I have examined several times the region between Spot Pond and Long Pond, where the stratified group meets the felsite to the southward, I have not been able to find the two rocks in place exposed nearer to each other than at the locality described; and although in the present state of our knowledge the existence of a "gradual transition" or intercalated felsite in the stratified group cannot be denied, it may be stated that careful search has not revealed to us the slightest evidence in favor of Mr. Crosby's positive assertion. It is hoped that the exposures which place such an important fact beyond question will be described in detail, so that other observers may obtain the evidence.

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* Contributions to the Geology of Eastern Massachusetts, p. 106.

Fortunately we need not depend for a knowledge of the relations of the rocks in question upon a region in which the absence of exposures along the line of contact renders it difficult to tell what may be true. Upon the northern boundary of the stratified group, from Break-heart Hill westward towards Main Street, the relations of the rocks are clearly exposed. Between Break-heart Hill and Main Street several distinct contacts of the felsite and quartzite may be seen, and there are no indications whatever of a transition between the two rocks. It will be remembered that, in describing Break-heart Hill, it was mentioned that the complex mixture of felsite and ashes extends from the summit down the southeastern slope to the rocks of the stratified group. Near the middle of the slope facing Mr. Edmond's house is a small ledge, furnishing an excellent exposure in which the felsite, with contorted banding, overlies unconformably at a large angle the upturned edges of the stratified group. The rocks beneath are in part quartzite interstratified with other rocks of the same group, and the line of contact sloping down the hill is well marked. A short distance to the eastward the banding in the felsite and the distribution of the ashy material has the same general slope as the plane of contact.

It seems to us that this very interesting exposure places beyond the possibility of a doubt the conclusion that the felsite is younger than the rocks upon which it reposes. A few rods to the southwest of the exposure just noticed there is another, which shows apparently one side of a dike of felsite cutting through the stratified rocks. The line of contact is very distinctly marked and irregular, like that of an eruptive rock, and is at right angles to the bedding of the adjoining rocks. Distinct fragments of quartzite belonging to the stratified group are enveloped by the felsite of this locality, and small ones have been found embedded in the ashes.

The facts observed upon Break-heart Hill are in harmony with the relative positions of the two rocks as determined by the relations of both to the granite, and there appears to be no doubt that the stratified rocks of Melrose and the adjoining towns are older than either the granite or felsite.

Having considered the relations of the older rocks to the felsites, let us turn our attention to the relations which the felsites hold to one another. Mr. Crosby has shown that the rocks of the group vary widely in chemical composition, and Dr. Wadsworth has called attention to the fact that upon Marblehead Neck the felsites are not all of the same age.

The stratified group which we have already described separates the adjoining felsites into two distinct areas, each of which includes several felsites of different periods of eruption. The felsite which is so intimately associated with the ashes upon Break-heart Hill occupies a considerable portion of the area east of Main Street, and between Break-heart and Little Castle Hills. A junction between the dark-colored felsite and a pale pink felsite may be traced across the northern part of Little Castle Hill, and southwest of this hill, about half-way to Main Street, another distinct junction occurs along which there is very well marked banding in the light-colored felsite, showing that it is the younger. Neither of these felsites is very porphyritic.

Within the southern area, a short distance southeast of Long Pond, Saugus, there is a small patch of a red, chiefly non-porphyritic felsite. The region immediately south of the pond, and to the southwest as far as the Boston and Maine Railroad, is occupied by a felsite which is generally very porphyritic. The ground-mass of this felsite varies somewhat in color, but it is usually light pink or pale purple, and besides being the most completely and uniformly porphyritic felsite of this region, very frequently envelops fragments of older rocks. It might properly be designated the porphyritic, pebble-bearing felsite, for these two features are comparatively uniform throughout the wide area occupied by this beautiful rock. The red non-porphyritic felsite, to which we have already referred, forms a very clearly marked junction with the porphyritic felsite about one fourth of a mile southeast of the eastern end of Long Pond, and the porphyritic felsite, which is distinctly banded along the line of contact, penetrates the adjoining red felsite, and envelops many of its fragments. Among the enveloped fragments in the porphyritic felsite are found a few of granite, — a fact which accords with those we have already discussed in showing that the granites are older than the felsites. The pebbles of the old felsite are numerous and widely distributed in the porphyritic felsite, and the evidence is so complete and well marked, that, as it seems to us, there can be no doubt that the two felsites were extruded at different periods.

About a third of a mile southeast of Swain's Pond in Melrose the porphyritic felsite is cut by a dike of what appears to be a third felsite, which is non-porphyritic and of a gray color. The dike has very irregular junctions, varies in width from a foot to eighteen inches, and can be traced across an exposure for a distance of thirty feet. The youngest of the felsites does not appear to have a very extensive development in that region.

Within the felsites many junctions of apparently different rocks may be seen; but because, as it appears to us, it may be possible for different parts of the same eruptive mass to form distinct junctions with each other, we were not inclined to accept junctions alone as evidence of difference in age unless supported by other facts. It appears to be evident, however, that not only at Marblehead Neck, as shown by Dr. Wadsworth, but also in each of the two areas of felsite we have explored, there were at least two distinct eruptions of felsite.

That some of the felsites are distinct in age is clearly shown also by their relations to the fragmental rocks, the so-called breccias, with which they are associated; but these relations can be considered to better advantage after the latter rocks have been described.

Fragmental Rocks.

The complex group of rocks included under the above name embraces those commonly called breccias in this vicinity, and is composed of members wholly distinct in origin and composition. The coarse fragmental rocks, whose fragments may be either angular or well rounded, are perhaps more abundant than the sandstone and finer-grained rocks. Most of these rocks are composed of fragments of highly altered igneous rocks, the felsites and granites, and properly belong to the tufas, or, according to Dr. Wadsworth's classification,* the porodites. There are, however, a number of localities where the conglomerate is composed chiefly of pebbles of quartzite from the stratified group.

The volcanic ashes to which we have already referred as occurring in the neighborhood of Break-heart Hill are undoubtedly of igneous origin, but in other regions the material is distinctly stratified, and must have been produced by aqueous agencies. Although we have no evidence which proves certainly the relative age of the ashes, it seems probable, from the fact that they are so intimately mixed with the oldest felsite, that they were produced about the same time with the felsite, and earlier than the stratified porodites (tufas) and conglomerates. It is sometimes extremely difficult to distinguish in the field between a recomposed rock and an eruptive one which has, at the time of its extrusion, picked up many fragments.† Only those exposures which are quite certainly of sedimentary origin will be noticed; although they are quite numerous, they are comparatively small. Mr. Crosby was the first to notice the stratification of these rocks, and pointed out the locality at Dungeon Rock, Lynn, where the material is fine, and apparently all derived from the felsites. Another similar locality in which the stratification is well marked occurs along the water-pipe between the reservoir and the water-works, Lynn. In these areas it is almost impossible to tell, upon a weathered surface, that the rock is fragmental. These exposures were accidentally brought to light by quite extensive excavations, and it is possible that some of what is now regarded as felsite may be a recomposed rock, so like felsite (from which it was made) in its external appearance as not to be distinguished from it by the unaided eye. The area of porodites and conglomerates of Vinegar Hill and Pirates' Glen is probably the largest area of these rocks in this region. In the same locality there are several small patches of granite mixed with the fragmental rocks which are in places distinctly stratified.

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* Bulletin of the Mus. Comp. Zoöl., Cambridge, Mass., Vol. V., No. 13, p. 280.

† See paper by the writer. Proc. B. S. N. H., Vol. XX. 355.

One of the most interesting exposures of the stratified porodites is upon a high hill, a short distance south from Saugus, and near the east side of the road leading to Sweetser's Corner. The greater portion of the hill is felsite, but upon its northern slope occurs the most beautiful coarse tufa of this region. It is tilted so as to be standing nearly or quite vertical, with a strike N. 70° E. At this place the thickness, measured directly across the strike, is about 150 feet, and may be greater, but for want of exposures the excess beyond 150 feet cannot be determined. This is the only locality we have found to furnish an opportunity to determine the thickness of the fragmental rocks.

An exceptional conglomerate occurs a short distance west of the Saugus station, near the railroad. Its peculiarity consists in its association with the granite, and that it is composed almost wholly of granitic débris. Some of the pebbles are large and well rounded, and the mass seems to lie directly upon the rocks from which it was derived. An unsuccessful attempt has been made to use this material for the bases of gravestones.

Between Cliftondale station and the Newburyport turnpike there is quite a large area of conglomerate containing a considerable proportion of quartzite pebbles. A smaller area of finer material occurs near the end of Granite Street, by the spring, about a third of a mile north of Maplewood.

A most interesting and varied locality in which the stratification is well marked may be found about a third of a mile southeast of Swain's

Pond in Melrose. Although the locality is small, it embraces a variety of fine-grained, red, argillaceous rocks, sandstones, and a very coarse conglomerate composed almost wholly of pebbles of quartzite from the stratified group.

In the base of a small hill a short distance northeast of Oak Grove station, on the Boston and Maine Railroad, the fragmental rocks of this group are well exposed. They extend into the base of Prospect Hill, and on the opposite side of the valley are exposed near the base of the Malden Highlands. Within the Highlands there are two small areas of tufas, one on each side of Highland Avenue along the Malden-Medford line. The conglomerate of West Medford, which is well developed along Purchase and Mystic Streets, resembles to a considerable extent some parts of the Roxbury conglomerate; but Mr. Crosby is most likely correct in connecting it with the fragmental rocks so intimately associated with the felsite.

Within the felsites north of the stratified group we have found only two small areas which, as it seems to us, are of sedimentary origin. One of the patches lies upon the first hill north of Oak Street, a short distance west of Nahant Street (Main Street), Wakefield, and the other is upon Candle-wood Hill, northeast of the Stoneham station on the Boston and Maine Railroad. It is very probable that a number of areas of sedimentary rocks have escaped our notice, but we feel sure they do not occupy the large areas over which they have been represented to extend. The very porphyritic felsite occupying the region lying between Long Pond, Saugus, and the Malden Highlands contains, as we have already stated, many pebbles of other felsites, and some of granite, but, like that at Red Rock, Lynn, it is by no means of sedimentary origin.

We have elsewhere * shown that some of the felsites are younger than the fragmental rocks so intimately associated with them, and it remains in this connection to point out the facts upon which this inference is based.

In the conglomerate about a fourth of a mile north of Cliftondale station there is a dike of pinkish felsite which is clearly eruptive through the fragmental rocks of the same locality. A similar phenomenon may be seen north of Oak Street, Wakefield, where a distinct tongue from the black-edged dike penetrates the adjoining fragmental rocks. The best locality, however, for observing the relations of these rocks is southeast of Swain's Pond, where the porphyritic felsite not only penetrates in the form of small, irregular dikes the fragmental rocks, but

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* Proc. Bost. Soc. Nat. Hist., Vol. XX., p. 364.

also in one exposure distinctly overlies them. This relation enables us to understand how it happened that the coarse quartzose conglomerate is completely surrounded by felsite which does not appear to have entered into its composition. The porphyritic felsite being younger than the fragmental rocks, it is not difficult to explain the fact that it contains so many pebbles. In Prospect Hill, Malden, and the small hill near by, just northeast of the Oak Grove station, the porphyritic felsite apparently overlies the fragmental rocks of the same locality. The dark-colored, less porphyritic felsite of the Malden Highlands is closely related to the porphyritic one to the eastward, and there is good reason to believe that the former, like the latter, is younger than the tufas of that region. The tufaceous rocks along the Malden-Medford line north of Highland Avenue are composed almost wholly of very silicious felsites, unlike those by which the small area is completely surrounded ; a fact which, as it seems to us, can be explained most satisfactorily by supposing that the dark felsite of the Highlands had not been spread upon the surface in its present position at the time the fragmental rocks were formed. The evidence we have given seems to us sufficient to fully establish the conclusion that some of the felsites are younger than the fragmental rocks with which they are intimately associated ; and on the other hand, it cannot be doubted that these fragmental rocks are more recent than the felsites of whose débris they are largely composed.

Diorite.

The diorite adjoins the felsite for only a few miles along the northwestern boundary of the latter, between Melrose Highlands and Smith's Pond (Crystal Lake), Wakefield. The line of contact is generally covered, and the two rocks were not seen upon the same exposure north of West Hill, near the Stoneham station * on the Boston and Maine Railroad. Upon this interesting hill we find a complex mixture of almost all the rocks of the region, and it appears to us that the diorite penetrates and envelops not only the stratified group, but also the granite and felsite. Distinct fragments of the granite and felsite have been seen in the diorite at several places. Similar phenomena may be seen upon the hills in Stoneham, near the south side of Franklin Street, where the eruptive diorite penetrates the granite, and cuts directly across the bedding of the stratified quartzites and schists. In that region the granites, diorites, and rocks of the stratified group are intermingled

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* The name of the post-office at Stoneham station is Melrose Highlands.

in a very complicated manner, but we have not been able to find any evidence which would lead us to suppose that there is a gradual transition from any one of the rocks into another of the same locality. It seems evident to us that the diorites are truly eruptive rocks, and that their extrusion has taken place since that of the granite and felsite which they penetrate.

Diabase and melaphyr, so abundant in the neighborhood of Boston, are found in very distinct dikes, cutting all the other rocks, and close the series of eruptive rocks in which there seems to have been, in the order of extrusion, a general progress from silicious to basic rocks.

The relative ages of the rocks in the region we have explored, as it seems to us, have been pretty clearly established, but the position of the whole series in the geological column is a matter concerning which we have seen very meagre and conflicting evidence. The slates, supposed by some to be primordial, lying between the Charles River and the hills of Medford and Malden, have not been found, so far as we know, in contact with the eruptive rocks to the northward. On the north side of the Saugus branch of the Eastern Railroad, between Faulkner's station and Maplewood, the slates are exposed within about one hundred and fifty feet of the hills of eruptive rocks upon the north side of Salem Street. The slates dip steeply (66°) to the northward, as though they were plunging beneath the other rocks. It may have been this fact which led Prof. John W. Webster, many years ago, to assert that the transition rocks (slates, etc.) were overlain by the porphyries of Malden.

In the rocks of the stratified group, so far as we know, fossils have never been found; and were it not for the fact that the Roxbury conglomerate contains numerous pebbles of quartzite, apparently derived, at least in part, from the rocks of the stratified group, I can see no good reason for supposing the stratified group to be pre-palæozoic. The same conglomerate contains pebbles of felsite, but whether any of them are from the felsites now exposed along the northern margin of the Boston basin is a question which, for its satisfactory solution, will require much more thorough and careful work than has yet been done in this region.

Conclusions.

The facts we have observed in the region described in the foregoing paper appear to establish, for that region, the following conclusions: —

The stratified group contains the oldest rocks of which we have any knowledge in that region, and, before the extrusion of the more recent eruptive rocks, they probably had a much wider distribution upon the surface than they now have.

The granites are not derived by metamorphism from any part of the series of rocks (stratified group) which they envelop, but are truly eruptive rocks, whose extrusion has occurred since the formation of the stratified group. Therefore the granites, as we know them in their present position, are younger than the stratified group.

The felsites are eruptive rocks, more recent than the granites. There were at least two eruptions of felsite in each area, and in the southern area there were probably three eruptions.

The fragmental material associated with the felsite upon Break-heart Hill is a volcanic ash; elsewhere the fragmental rocks have generally been formed of material eroded and deposited by water.

The very porphyritic felsite between Long Pond and Prospect Hill, part of the felsite of Wakefield and at Cliftondale, and probably the dark-colored felsite of the Malden Highlands, are younger than the tufas and conglomerates with which they are associated.

The diorites are eruptive, and younger than the felsites.

The diabases and melaphyres are the youngest eruptive rocks of this region, and there has been, in the order of eruption beginning with the granites, a general progress from silicious to basic rocks.

No. 3. — *On an Occurrence of Gold in Maine.* *By* M. E. WADSWORTH.

THE gold under consideration here is found on Seward's Island, a small island in the town of Sullivan, Hancock County. The gold is found in quartz veins cutting an eruptive mass of diabase. This diabase forms a dike of about 40 feet in thickness, lying approximately parallel to the bedding of an indurated fine-grained argillaceous mica schist; all dipping nearly S. 30° W., 24° to 42°. The dip averages about 35°, and the strike is far from being uniform. Crossing the diabase at various angles, but generally from north to south, are segregated quartz veins. In some places the rock is a confused reticulated mass of these veins, with patches of diabase lying between them. The veins vary in width from a mere seam to even a foot in breadth. Starting where only one or a few of them are visible, they gradually increase in number until they become quite numerous, while they will doubtless be found to fade away as they began. The diabase and schists are cut by several dikes of diabase running approximately at right angles to the strike of the schist, or parallel to the veins. The vein stone is quartz, together with some calcite, tremolite, and chlorite, and carries tetradymite and gold.

So far as examination has been made, the veins in the diabase carry gold, and the decomposed diabase immediately adjacent to the quartz veins also contains that metal to a greater or less extent. The gold occurs principally in small grains in the vein in connection with the tetradymite, bits of decomposed diabase, and in the cavernous portions, but not in the compact quartz of the vein itself. The tetradymite is in irregular grains and masses, showing a brilliant metallic lustre and a well-marked basal cleavage. The locality is worked for its gold, and was visited by the writer in December last.

CAMBRIDGE, MASS., January, 1881.

No. 4.—*A Microscopical Study of the Iron Ore, or Peridotite, of Iron Mine Hill, Cumberland, Rhode Island.* *By* M. E. Wadsworth.

The attention of the writer was first particularly called to this formation by some specimens presented to him by Mr. H. B. Metcalf in the spring of 1880. These did not appear to the writer to be any common ore of iron, but rather fragments of a basic eruptive rock containing much iron. Sections were accordingly made which revealed its true character.

The formation was described by Dr. Charles T. Jackson in his report on the Geological Survey of Rhode Island in 1840. He states that Iron Mine Hill "is a mountain mass of porphyritic magnetic iron ore, 462 feet in length, 132 feet in width, and 104 feet in height above the adjoining meadow. From these measurements, which were made over only the visible portion of this enormous mass of iron ore, it will appear that there are 6,342,336 cubic feet of the ore above natural drainage. . . . Its specific gravity is from 3.82 to 3.88. . . . This ore is remarkable both on account of its geological situation and its mineralogical and chemical composition. It appears to have been protruded through the granite and gneiss at the same epoch with the elevation of numerous serpentine veins which occur in this vicinity. This will appear the more probable origin of this mass, when we consider its chemical composition in comparison with that of the iron ore, which we know to have been thrown up with the serpentine, occurring on the estate of Mr. Whipple, and the fact that the ore at Iron Mine Hill is accompanied by serpentine mixed with its mass in every part, gives still greater reason for this belief." (*l. c.*, pp. 52, 53.)

He gives as the result of his chemical analysis of the "Porphyritic Iron Ore from Iron Mine Hill, Cumberland," the following (*l. c.*, p. 53) :—

SiO_2	23.00
Al_2O_3	13.10
Fe_2O_3	27.60
FeO	12.40
MnO	2.00
MgO	4.00
TiO_2	15.30
H_2O and loss	2.60
Total,	100.00

In 1869 the Rhode Island Society for the Encouragement of Domestic Industry published a report relating to the coal and iron in Rhode Island, from which we glean the following. The iron ore is regarded as practically inexhaustible, the mass at Iron Mine Hill visible above drainage being estimated at two millions of tons.

"It is also conceded, as regards quality, that the Cumberland ore is free from sulphur and phosphorus, the most common and worst impurities, and that it contains manganese, the most prized of all the elements found in connection with iron. For these reasons the Cumberland ore is sought by manufacturers at a distance, to mix with softer ores and improve their quality, and is now exported from this State for that purpose."

It seems that this Iron Mine Hill ore was employed in 1703, mixed with the hematite of Cranston, R. I., for the casting of cannon. The work was done at Cumberland, and, in part at least, "the cannon used in the celebrated Louisburg expedition, in 1745," were cast from these ores. The manufacture was abandoned in 1763, owing to an explosion of the furnace, by which the proprietor was killed.

During the administration of John Adams the same ores were also used for the manufacture of cannon. It seems that the Cumberland (Iron Mine Hill) ore was employed in the manufacture of charcoal iron at Easton, Chelmsford, and Walpole, Mass., as late as 1834. "The Cumberland ore, mixed with equal quantities of Cranston hematite or bog ore, produced, for a long period, a charcoal iron unsurpassed in this country. . . . The Cumberland ore contains an uncertain percentage of titanium, which, while it improves its quality, helps make it refractory. The ore is porphyritic, the magnetic oxide being associated with earthy minerals, principally feldspar and serpentine." It would seem that in 1869, and before, the ore was largely shipped to Pennsylvania to mix with other ores.

A letter of Professor R. H. Thurston, published in this report, states: "The Cumberland iron ore is of the kind known to mineralogists as 'ilmenite'; among metallurgists as 'titaniferous magnetic ore,' and iron manufacturers, on account of its peculiar value for producing steel, would term it a 'steel ore.' . . . The Cumberland ore is conveniently located and of inexhaustible extent; it is perfectly free from noxious elements, though somewhat refractory; it will furnish a very strong iron or a most excellent steel; it can be smelted within the State at a profit; it can be made directly into steel at a much greater profit; steel made from it will bring the highest prices in the market."

Professor Thurston states that the mean of various analyses made of this ore is about as follows: —

SiO_2	22.87
Al_2O_3	10.64
Fe^2O^3	44.88
FeO	
MnO	2.05
CaO	0.65
MgO	5.67
TiO	9.99
Zn	0.20
H_2O and loss	3.05
Total	100.00

The ore on one side of the hill, where it has been most extensively quarried, shows a dark, somewhat resinous groundmass, holding large striated crystals of feldspar. The resinous lustre and greenish-yellow color, as observed under the lens, are caused by the presence of olivine. The olivine becomes more strongly marked on the slightly weathered surfaces seen on the faces of the quarry. Under a lens of high power, the olivine shows clearly on the fresh fractures. The olivine in weathering decomposes to a yellowish and reddish-brown ferruginous powder, leaving the other constituent of the rock, the magnetite, well marked. The magnetite decomposes more slowly, and forms an incoherent mass after the decay of the olivine. The rock gelatinizes with hydrochloric acid, and yields a titanium reaction. A fragment allowed to stand a day or two in weak hydrochloric acid yielded gelatinous silica copiously.

A section made with special reference to the feldspar crystals shows large porphyritic crystals of the latter enclosed in a mass of magnetite and olivine.

The magnetite forms irregular, more or less connected masses, making a sort of sponge-like structure. Its rounded and irregular cavities are filled with olivine, which also occupies the interspaces between the magnetite masses. The olivine is in rounded forms, which sometimes show one or more crystal planes. It is cut through by numerous fissures, that usually show a ferruginous staining along their sides. The olivine also holds grains of the magnetite. Except the fissuring and ferruginous staining, the olivine is comparatively clear, and shows little signs of alteration.

The plagioclase feldspar shows well-marked lines of cleavage and fracture, and is somewhat kaolinized along these lines. It contains a few irregular flakes of biotite together with grains of olivine and magnetite.

The order of crystallization appears to have been, first the magnetite, then the olivine, and lastly the feldspar.

This rock is similar to the celebrated iron ore of Taberg, Sweden, as described by A. Sjören in the Geologiska Föreningens Forhandlingar (1876, III. 42 – 62; see also Neues Jahrbuch für Mineralogie, 1876, 434, 435). The Taberg rock has been worked as an iron ore for over three hundred years. This Swedish ore is called by Sjören "magnetite-olivinite."

The feldspar is confined to the peridotite found on one side of the hill, where the peridotite passes into a compact greenish-black rock, showing patches of serpentine and grains of magnetite. From this fact it seems necessary to regard the feldspar as abnormal and local in the rock, which in general is composed of olivine and magnetite or their alteration products.

The structure remains about the same in the non-feldspathic portions as it is in those before mentioned as holding feldspar. But the olivine is entirely changed to a greenish serpentine which shows beautiful fibrous polarization. The serpentine retains the form of the olivine grains, their inclusions, and the network of fissures before mentioned. In some of the sections considerable carbonate was seen, presumably dolomite. In one section part of the olivine grains, especially towards their interior, remained unchanged, but on their edges they were altered to serpentine. Another change was observed here: the formation of secondary crystals of irregular outline that belong probably to actinolite. Some are elongated and narrow; others are short and broad, traversed by cleavage planes. They evidently belong to the monoclinic system.

The origin of this rock could not be told from its field relations, as its contact with any other rock could not be found. Since the only method in which its origin can be absolutely shown cannot be used without expensive excavation, it only remains to give the probabilities so far as ascertainable from the mass itself. Such microscopic characters and mineral association have been, so far as we know, only found in eruptive rocks when the origin of such rocks has been studied with sufficient care to determine it. Hence we must conclude it is most probable that this mass is eruptive also, until found to be otherwise.

It closely resembles in structure and composition some of the meteorites, except that its iron is oxidized and not in a native state, — a resemblance which for others of the peridotites has long been pointed out.

It is rocks of this character, as has been suggested by others, that give us the most probable clew to the interior composition and structure of the earth.

The rock in the field shows, to our mind, no signs of structural planes that should be referred to sedimentation. On one side the rock is massive and jointed, and on the other it is jointed in fine parallel planes. This portion of the rock is more highly metamorphosed than the other, and, as is usual in highly altered eruptive rocks, joints parallel to certain lines of pressure occur. The writer has seen this structure in many rocks that were indisputably eruptive, forming well-marked dikes in other rocks.

A rod away from the main mass of the iron ore, near one end, some serpentine appears that cannot be directly connected with the other peridotite. Microscopically its characters and structure are the same as the main rock, and there is no reason to regard it as distinct. The rock nearest to the peridotite is a mica schist some hundred feet away. It shows no characters that would indicate the transition of the ore into it.

The locality was visited by the writer in October last, in company with Professor A. S. Packard, Jr., of Brown University, and Mr. T. S. Battey, of the Friends' School, Providence, R. I. To the latter gentleman I am especially indebted for a copy of the paper of the Rhode Island Society before mentioned, and for other favors.

This examination may serve as an illustration of the aid that microscopical lithology may be to the practical side of life, since now, for the first time since this rock has been worked, can the ironmaster who wishes to use it approach understandingly the metallurgical problems it presents; whether he desires to employ the rock as a whole, or to concentrate the magnetite first.

CAMBRIDGE, MASS., May 13, 1881.

No. 5.— *Observations upon the Physical Geography and Geology of Mount Ktaadn and the Adjacent District.* By C. E. Hamlin.

The "Geological Map of Northern Maine," that accompanies the "Preliminary Report upon the Natural History and Geology of the State of Maine," for 1861, represents Mount Ktaadn* as included in a large granite district, of which it is the culminating height. The area, as delineated, is an ellipse, the axes being respectively about twenty and forty miles in length, — the major axis running very nearly in a northeast and southwest direction. Between the most northerly of the two foci and the northeast border of the district, Ktaadn is placed; while between the other focus and the southeast margin are situated the "Ebeme Mountains," so called by the compiler of the map. The Penobscot River, in a course intermediate with the two axes and oblique to each, crosses the intervening country, which has a general elevation of not more than 550 feet above sea level, and is thickly sown with lakes.

An excursion, of which this paper states results, was made in August last, along a route that passes through nearly the whole length of the supposed granite area. The special purpose of the writer at the outset was to compare the granite of the lower grounds with that of Ktaadn itself, which had been partially studied in August, 1879, and less carefully in 1869 and 1871; to find, if possible, at some points, the junction of the granite with the surrounding stratified rocks; and to continue the exploration of Ktaadn with reference to completing the model of the mountain, of which a heliotype is herewith presented. The route selected comprises the northern seven miles of Schoodic Lake, fifteen miles of forest travel to the Middle Joe Merry Lake, a course through this, the Lower Joe Merry, Pemadumcook, and Ambejijis Lakes and their connecting "throughfares," and nine miles up the Penobscot to the mouth of the Aboljacarmegus Stream, where the ascent of Ktaadn begins. From the terminus of highways at Brownsville, the route measures about fifty miles in length.

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* The spelling *Ktaadn* is adopted in accordance with an opinion communicated to the writer by J. Hammond Trumbull, of Hartford, the most eminent living authority upon Indian dialects. Dr. Jackson, Thoreau, and a few others, have previously used the same form.

As almost nothing definite is on record respecting the depths of the lakes that cover so large a portion of Northern Maine and British America, soundings as numerous as circumstances permitted were made of the lakes traversed. And though the Geological Reports represent the lakes above named — except the first, of which no account has appeared in print — as enclosed by shores made up of loose material, it was thought best, in consideration of the remarkably low stage of water then prevailing, to re-examine the shores and beds of the lakes in regard to their composition. The same course was adopted for the Penobscot River, especially at the five falls and portages that intervene between Ambejijis Lake and Aboljacarmegus Stream.

The Lakes.

Schoodic* Lake, which shares its name with the larger Schoodic lakes that lie on the eastern border of Maine, is in some respects the most interesting of all that occur in this region. In his "Water Power of Maine," Wells gives its area as sixteen square miles, and it is said to have a length of ten miles, and in its central part to be two and a half miles wide. It is free from islands, except at a single point upon the eastern shore; and the forest that surrounds it shows no break in its continuity, nor any other sign of settlement. The absence of islands from the main body of the lake indicated deep water; but the rough condition of the surface, when we boated over it, prevented us from trying the depth. Our guide, Mr. Clapp, was employed to sound the lake on his return, and the list of his numerous and careful soundings shows it to be by far the deepest of all the lakes through which our route lay. The part over which we passed is enclosed by shores of granitic detritus, and there was nowhere to be seen any outcrop of the slates that underlie the whole surrounding district.

From the Schoodic to the Middle Joe Merry, our way was along a logger's road through continuous forest, which occupies a land surface very level and entirely drift-covered, not one exposure of ledge being observed in the whole distance of fifteen miles. Since our course through the series of lakes will be apparent from inspection of the accompanying map, no more need be said of it than that, favored in general by absence of wind, which, in a brief space of time, raises on these lakes a sea dangerous to boats, our examinations were continued from Pemadumcook Lake to the foot of the North Twin, whence, returning to Ambejijis Lake, we proceeded up the Penobscot.

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* The name as applied to this lake is probably a refinement upon an earlier one, found on the older maps, that of *Skootum* Pond, itself perhaps the corruption of some now unknown Indian name.

For the first ten days our party consisted of six persons, two boats' crews; — one made up of my companion in two former trips to Ktaadn, Dr. Crosby, of Waterville, Me., his son and nephew; the other, of Mr. L. E. Blake, of Worcester, Mr. Clapp, and myself. In sounding lengthwise of the lakes, our boats often took opposite sides, and, landing frequently upon the shores and islands, we carefully viewed the unusually wide extent of rocky surface laid bare through the long-continued drought. Very nearly the same conditions observed in one were found to prevail in all the other lakes and their connecting streams. All are bordered by detrital deposits, constituting occasional sandy or pebbly beaches of small extent, but ordinarily made up of granite bowlders having angles but little rounded by attrition, and which are often so crowded together as to resemble walls. The smaller islands that stud the lakes are sometimes banked up on all sides, or wholly covered over, with bowlders that have been borne to their present resting-places by the action of ice in successive winters.

The only occurrence of rock in place, upon any of the lakes and throughfares visited, was observed later upon the Upper Joe Merry, which lay to the west of our route from Schoodic Lake to the Middle Joe Merry. On the return of Dr. Crosby and his companions, at the end of ten days, they "carried" from the Middle to the Upper Joe Merry, which has a length of about three miles. An examination of its margin, made at my request since I was myself to return from Ktaadn by the Aroostook route, discovered upon a projecting point a granite ledge, which for seventy-five feet forms the shore, rising steep ten feet from the water. The southern half of the lake was crossed, but, with the exception named, only shores of drift were seen. Soundings were at the same time taken, which will be given in the tables of depths.

Ambejijis Lake, uppermost of the series of expansions of the Penobscot known as the Pemadumcook chain of lakes, and but two miles long by three fourths of a mile wide, receiving directly whatever of detritus is swept down by the rapid river above, might be expected to be shallower than the rest. It proved, however, to be deeper than the average of the others, and here at one place was made the deepest sounding, 51½ feet, that occurred in the series. This lake was once a connecting link between Pemadumcook and the larger Millinoket Lake on the east, which, according to Wells, has an area of eighteen square miles, while to

Pemadumcook, including Ambejijis, is assigned an extent of sixteen square miles. The whole constituted one lake with two outlets, a case rare in Maine. The formerly connected lakes are now separated by a wide lagoon and a bush-grown sand-flat of four rods wide, products of detritus brought down by the river. In times of flood, boats still pass freely from one to the other. Millinoket at present has for its outlet a stream bearing the same name as the lake, which, rising from the eastern end, flows south into Shad Pond, the lowest lake-like expansion of the Penobscot. The lagoon, through which in 1871 we were barely able to thrust our light boats, was now a broad surface of mud, impassable by boat or on foot, and an effectual barrier to the extension of our soundings and exploration into Millinoket. That this lake, as to its surroundings, is not unlike the neighboring ones, we are confident from our recollections of a pretty careful examination of it made in the previous visit. They agree with the statement of Dr. Jackson, that "the islands are composed of the detritus of granite rocks, and the shores are composed of the same materials."* Seen from the summit of Ktaadn, the outspread Millinoket presents in a marked degree those flowing outlines of gently rounded bays which distinguish lakes enclosed by detritus from the angular, irregular, and often narrow recesses that are said to characterize lake basins excavated in solid rock. Of the latter class I know not an instance in Maine.

The following tables register soundings made at intervals in what appeared to be the deepest parts of the lakes we navigated. Casts were made from the two boats, running some distance apart, and commonly in nearly parallel lines. The columns marked A contain the results of soundings taken by myself, with the assistance of Mr. Blake. The columns B give soundings made by Mr. C. B. Wilson from Dr. Crosby's boat. The figures show that the lakes represented, with the notable exception of Schoodic, have bottoms that are generally flat; and noting the nature of the materials that compose the shores, the lake beds would seem to be hollows, which had their origin in irregular accumulations of drift deposited on broad, flattish surfaces.†

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* Second Report on Geology of Public Lands, 1838, p. 11.

† G. W. Taylor, Esq., a resident of Cazenovia, Madison County, N. Y., writes as follows respecting Cazenovia Lake, which is one of the feeders of the Erie Canal, and situated in a valley surrounded by hills:—"Mr. Ledyard, one of the old inhabitants, made many soundings before I came here to reside. The bed of the lake [four miles long by three fourths of a mile wide] is as level as a valley; about one third of its area varies in depth only from 43 to 46 feet, — the latter being the greatest depth. The south end [the foot] of the lake is quite shallow."

I. *Upper Joe Merry Lake.*

		Ft.	In.
Off east shore, from middle of that shore to south end of lake	1	28	
	2	32	
	3	36	
	4	38	
	5	42	
	6	43	4
	7	44	8
	8	44	
	9	40	
	10	38	
	11	32	
	12	26	
South of South Island	13	38	
	14	36	
	15	34	
	16	40	
West of South Island	17	36	6
	18	40	
	19	42	
North of South Island	20	42	
	21	40	
	22	38	
East of South Island	23	36	
	24	38	
Up centre of lake from south end	25	40	
	26	42	
	27	44	
	28	42	
	29	40	

II. *Middle Joe Merry Lake.*

Running along central part from lagoon on south to vicinity of outlet at north.

A.

	Ft.	In.
1	10	
2	10	
3	15	
4	15	
5	14	8
6	14	7
7	15	3
8	15	
9	11	
10	15	
11	14	11
12	13	
13	16	4
14	18	
15	18	2
16	17	
17	16	
18	17	

B.

	Ft.	In.
1	14	4
2	14	6
3	16	3
4	13	9
5	7	
6	9	11
7	16	4
8	6	
9	13	8
10	12	
11	15	10
12	16	7
13	18	

III. *Lower Joe Merry Lake.*

From entrance on south, along middle 1½ miles to northwest, till stopped from sounding by wind.

A.

	Ft.	In.
1	20	4
2	22	2
3	22	4
4	10	6
5	25	
6	29	7
7	30	
8	30	7
9	33	1
10	33	

B.

	Ft.	In.
1	15	4
2	16	5
3	20	4
4	22	4
5	20	
6	20	
7	21	
8	23	10
9	24	2

IV. *Pemadumcook Lake.*

Running southeast toward foot, west of middle. Soundings began off small island near mouth of Lower Joe Merry outlet, and continued 2½ miles down, till stopped by wind.

A.

	Ft.	In.
1	13	
2	15	8
3	23	5
4	37	
5	29	4
6	28	7
7	15	10
8	24	4
9	20	10
10	17	
11	17	3
12	14	7

B.

	Ft.	In.
1	13	
2	23	
3	36	6
4	30	
5	28	2
6	24	9
7	23	
8	17	

From foot, east of middle, in northwest course, about four miles, nearly to Gull Rock on east shore, opposite mouth of Lower Joe Merry outlet.

A.

	Ft.	In.
1	12	9
2	13	
3	12	5
4	11	7
5	15	8
6	17	5
7	21	
8	21	6
9	19	6
10	16	4
11	23	2
12	23	6
13	23	9

B.

	Ft.	In.
1	21	4
2	22	

V. *Ambejijis Lake.*

Along middle, from foot, north to head, about two miles.

A.			B.		
	Ft.	In.		Ft.	In.
1	9	3	1	7	
2	10	4	2	18	
3	10	1	3	35	4
4	15	9	4	44	6
5	14		5	35	3
6	16	9	6	37	6
7	25	4	7	25	4
8	26	9			
9	30				
10	51	6			
11	26	4			
12	25	7			

Cast 12 was quite distant from 11, and near entrance of Penobscot into lake.

VI. *Schoodic Lake.*

Numbers 1 to 25 give soundings from south end north, along course of west shore, but well out from it; 26 to 38 were taken off east shore, going from south to north; 39 to 50 are soundings made in March, 1881, through holes cut in ice along centre of lake, from south to north, at intervals of half a mile. Taken by Mr. Isaac Clapp, who speaks of his soundings as showing that "there is a mound near the centre of the lake 105 feet high," above the adjacent deepest parts.

		Ft.			Ft.
1		37	26		120
2		65	27		120
3		100	28		97
4		100	29		100
5		87	30		104
6		86	31		106
7		63	32		100
8		25	33		70
9		28	34		63
10		16	35	Off Five Islands	100
11		12	36		95
12		17	37		95
13		56	38		28
14		72	39		110
15		70	40		140
16		79	41		140
17		90	42		142
18		90	43		73
19		100	44		40
20		51	45		145
21		37	46		100
22		39	47		90
23		28	48		120
24		28	49		122
25	At north end	14	50		90

VII. *North Twin Lake.*

Soundings taken by Mr. Wilson, along middle, from north to south, about two miles. Mine were lost.

	Ft.	In.
1	19	
2	18	3
3	16	
4	22	4
5	23	
6	22	4
7	19	6
8	19	

An Unreported Kame.

From a spot on the western shore of Middle Joe Merry Lake, known to the guide as Gordon's Landing, a name derived from former lumbering operations, a "horseback," or kame, runs two and a half miles north 28° west, forming for some distance the shore of the lake. On examination it proved to be an interesting specimen of its kind. It slopes at each end gradually to the general level, but through all the central portion maintains a tolerably uniform height. At a fairly representative point, it was found to have at its slightly rounded top a width of 15 feet, and by use of a clinometer and level the inclination of the east side was ascertained to be 30°, and the height 39 feet above the lake. The west side has an angle of 25° and rises 26 feet above an old pond of equal length with the kame, now changed to a swamp, only the width of the kame intervening between the swamp and the lake. Many granite bowlders of from one to two feet or more in diameter are strewn upon the ridge at and near its summit. The smooth and unbroken surface of the kame seems to indicate rather that they were deposited upon the ridge subsequently to its formation, than that, having made part of the original structure, they were by denudation left projecting from its surface.

The Granite Area.

Doubts respecting the actual existence of the granite area represented in the geological map were suggested during a rapid passage, in 1869, over the route now taken. The facts already stated, so far as they bear on the theory of such an area, do not go to sustain it. The observations now to be noted are more closely related to it.

From Gordon's Landing an excursion was made to Joe Merry Mountain, which is situated well within the limits of the supposed granite district, and is nearest and highest of the elevations that lie west from the chain of lakes. Showing upon its sides, as it does, bare cliffs through the forest that covers it, this mountain was chosen as a locality where we might hope to find some evidence of the nature of the rock underlying the vicinity, which, at the lower levels, had been hitherto concealed by thick drift deposits.

Dr. Jackson, while on his way to Ktaadn in 1837, saw this mountain from the shore of Ambejijis Lake, and describes it in these words: "From this spot I took a view of Joe Merry Mountain, which appears rising to a considerable elevation on the southwest. . . . . It is composed of granite, and is a commanding point of view for examining the surrounding country, so that it is frequented by explorers for timber." * But as Jackson was never nearer to it than when he ran down Pemadumcook Lake on the return from Ktaadn, it is evident that this statement rests merely on report.

A circuit of seven miles through the woods brought us to the foot of the mountain on its north side, where it rises at a sharp angle from the valley. For the last four miles of our way up to this point, the ground was thickly strewn with granite bowlders, which became larger and more numerous as we approached the mountain. So far neither rock in place, nor bowlders of other material than granite, had anywhere been seen. But, 200 feet up from the foot of the steep northern face, we began to find mingled with the granite bowlders others of considerably altered mica schist. At the height of 450 feet, and again at 600 feet, above the base, we came upon exposed ledges of rock, the same in kind as the newly found bowlders. So far the ascent had been abrupt. For the next hour it was more gradual, and several small levels and depressions were traversed. Later, a narrow and deep ravine was crossed, having on its farther side a cliff of schist, similar to that observed below, which rose at an angle of 35°, and so high as to require twenty minutes' sharp climbing to gain its top. Thence a gentle ascent was followed for ten minutes, when an elevation was attained of 1,635 feet above the lake, as determined by means of an aneroid, whose readings at various points were compared with simultaneous observations made by Mr. Blake with a Green's mountain barometer stationed in camp at Gordon's Landing. At this height numerous granite bowlders were still scattered over the mountain top. The mountain is a long ridge, running north and south. Its actual summit now lay

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* Second Report on Geology of Public Lands, p. 13.

perhaps half a mile before us, but scarcely more than 150 feet higher than the point already reached. As it was covered with forest, and promised neither outlook nor further revelation of the lithology of the mountain, and as our time was exhausted, we advanced no farther, but returned to the lake.

From the head of Ambejijis Lake, the route to Ktaadn for the next nine miles follows the Penobscot. For this distance, and in fact all the way from Shad Pond, below, to Chesuncook Lake, the river at short intervals widens into still lakes connected by rapid, rocky, and narrow reaches of running stream. As related to the falls and rapids, each of the numerous lake-like expansions is styled by rivermen a "dead-water." These remaining nine miles of water route include five falls, requiring as many portages of from twenty to ninety rods in length, each fall having below a dead-water bearing the same name as the fall itself. Thus Ambejijis Lake is the dead-water that lies below Ambejijis Falls.

While the prevailing and excessive drought greatly retarded travel upon the river, it afforded an unequalled opportunity to learn the nature of its bed, now bare to an extent unknown before for many years. One's conclusions with regard to the geology of the district south of Ktaadn must be shaped largely by the view he takes of the facts that relate to the nine miles of river bed here referred to. And since the previously recorded examinations of this part of the river were made in haste, and at times when high water in great measure hid the channel from observation, it seems best to state the very simple facts somewhat in detail.

Ambejijis and Passamagamet Falls, first in order, and a mile and a half apart, are caused by accumulations of large granite bowlders that choke up the narrow channel and give origin to the dead-waters next above them. To remove the bowlders would be to draw off the waters of those pond-like expansions. Not a trace of rock in place could be discovered in the river bed at either of these falls, nor upon the adjacent shores, which are elevated but a few feet above the level of the river.

The first ledge that appears upon the river or its expansions, from the foot of North Twin Lake northward, occurs twenty rods below the third, or Katepskonegan Falls, longest of the series, stretching seventy rods along the course of the river. The ledge, which is of granite, rises on the eastern shore directly from the water in a precipitous head of twenty feet in height. Northward to the falls, the east shore is a steep extension of the head, which inclines downward to the north, till at the falls themselves the ledge is to be seen only on the floor of the river bed. There is no exposure of granite upon the western side to match the high head upon the eastern; neither could rock in place be detected in the low banks of drift abreast the falls, nor along the carry. In the channel at the foot of the falls, the ledge was mostly hidden by accumulated granite bowlders, while at the upper part the water was seen to pitch over successive shelves of granite in place.

Though it was here that we first came upon fixed rock in the river bottom or banks, we had seen, half-way between this and the next fall below and some distance back from the west shore, two high forest-covered hills, which were the first considerable elevations met with since we left the lakes below. On the southern slope of each hill is a naked cliff. Circumstances rendered it impossible to land and push through the woods for a visit to the cliffs; and no second view of them occurred, since my return from the region took place by another route.

The passage through the dead-water of more than two miles to the fourth fall showed no trace of rock in place, either in the channel or along the shores. Nor did the neighboring low hills exhibit any faces of exposed rock.

Pockwockamus Falls, the fourth, occupy about twenty rods of the river's length, beginning abruptly from still water above, and ending as abruptly below in water of like character. The bed is an uneven floor of granite ledge, measurably free from bowlders in the middle third, but on each side covered with large blocks, mainly riven from the underlying fixed rock, which does not differ materially from that of the third fall.

At the fifth or Aboljacarmegus Falls, a mile above the fourth, is the next exposure of rock *in situ*. The river makes here a sudden bend, flowing from northeast to southwest, and is exceedingly narrow. The length of the fall is ten or twelve rods only, and the underlying granite differs strikingly from that of the third and fourth falls, and from that which makes up Ktaadn. In places it is highly porphyritic, and occasional patches of several square feet consist of massive feldspar or quartz, not constituting veins. At the third and fourth falls the granite, being highly jointed, has become divided into rhombohedral blocks of all sizes. Worn at the angles in various degrees by attrition, these make a large proportion of the bowlders that at both those falls conceal the rock in place over much of its area. At the fifth fall the fragments split from the solid mass in somewhat lenticular forms, never in rhombohedral blocks. About the foot, the only pot-holes anywhere seen occur in considerable number, but not of great size. Their presence here and absence from the falls below must be explained by difference in the texture of the rock at the localities, rather than by difference of other conditions. Along the portage past this fall are several small exposures of granite ledge, the only ones that were seen near the river, apart from its bed or banks.

The granite of the three ledge-formed falls, as well as that of Ktaadn, beyond any other that I have elsewhere seen, is free from veins and dikes. In fact the only instances observed of either in the whole region were a quartzose vein, an inch wide, that ran through a block twenty feet in length, evidently torn from the rock on which it rested at the fourth fall; and a small trap dike, four inches wide, that traversed a nearly buried erratic bowlder lying on the portage at the fifth fall.

Another circumstance common to the granite of the several localities is, that at the falls only is it visible. Above and below each fall the rock so suddenly and entirely disappears, that over the spaces between the falls granite in place could nowhere be discovered. It would seem, then, that at the third, fourth, and fifth falls a ridge of granite in each case cuts the river bottom transversely, damming the stream and obliging it in its course seaward to tumble in a fall over the lower slope of the ridge. The underlying fixed rock which intervenes between the granite ridges is so hidden by drift deposits that nothing can be asserted positively concerning its nature. One would naturally suppose it to be granite; but without attaching much importance to the marked difference between the rock of the upper fall and that of the two next below, there are other considerations, to be noticed presently, which suggest a doubt whether the three ridges that occasion the three ledge-formed falls have any lateral connection below the drift, and the question whether they may not be distinct ridges of intrusive rock, thrust up through strata from a common source beneath.

The theory that the district south of Ktaadn is part of a continuous granite region, is a hasty generalization from insufficient data, originally made by Dr. Jackson. Prof. Hitchcock, in his survey, which was discontinued at the close of its second year, made no personal examination of the Penobscot valley between Chesuncook Lake and Grand Falls. He therefore naturally adopted in the construction of his geological map Dr. Jackson's view of that district, supplemented by some testimony of one of his own assistants. The map was of course intended to be provisional only, and, had the survey been continued, would probably have been superseded by others. All the basis that exists for belief in a wide granite area south of Ktaadn is found in a few passages of Jackson's and Hitchcock's Reports. They can here be presented in small compass.

Jackson's notes of his trip to Ktaadn contain only the following brief statements respecting the rocks *in situ* which he saw on the way to and from the mountain. First, the one previously quoted in full, that Joe Merry Mountain "is composed of granite."[*] Second, that, "leaving our boats, we walked to Pock-wock-amus Falls, where the river rushes over a ledge of granite."[†] Third, "All the rocks at Quakish Lake[‡] are granite, and the water falls over huge bowlders of that rock."[§]

Dr. Jackson's assistant, Mr. J. T. Hodge, had preceded him by three months in the passage up the river. He speaks of but one of the two hills I have described as lying west of Katepskonegan Dead-water, saying: "On its western side is a high hill of granite, covered with immense loose blocks of the same rock, piled one upon the other almost perpendicularly." He adds: "Two miles above [a fall over "loose granite rocks"], we were obliged to carry by again on the western side. The opposite bank is formed of granite . . . . lying in the best position and form for working." Continuing, he remarks: "Not far above this we arrived at a fifth portage, which is called the Pauquakamus [in fact Aboljacarmegus]. . . . . At the head of this portage, the bank is a smooth ledge of granite."[||]

Mr. J. C. Houghton, who for the year 1861 was Hitchcock's assistant, furnished for his report the following facts. In the account of a trip from Moosehead Lake down the Penobscot to Ktaadn and beyond, he notes that at the fourth and fifth portages "the river falls over ledges of fine granite."[¶] Respecting the fixed rocks upon the river and lakes below, he makes no further remark than that "near the outlet of North Twin Lake is the southeast limit of the granite, and the quartz rock [which he had last seen between Chesuncook and Ripogenus Lakes] again appears."[**]

Elsewhere Mr. Houghton mingles facts and conjectures. Having visited the "Katahdin Iron Works,"[††] which are situated in the township that corners upon Brownsville at the northwest, he proceeded twelve miles farther northwest to a remarkable gorge, known as the "Gulf." This has been cut by Pleasant River for five miles through black slate that rises on either side in walls, sometimes to the height of from 100 to 300 feet, often vertical or overhanging.

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[*] Second Report on Geology of Public Lands, p. 11.

[†] Ibid., p. 14.

[‡] Quakish Lake on Hitchcock's map is placed outside of the granite district, the last granite in place being now known to occur a little below North Twin Lake, *above* Quakish.

[§] Ibid., p. 20.

[||] Ibid., p. 53.

[¶] Prel. Rep. Nat. Hist. and Geol. of Maine, p. 440.

[**] Ibid., p. 440.

[††] A confusing misnomer, since they are situated full thirty miles in a straight line from the mountain whose name they bear.

He next "ascended Saddle Rock, a mountain which is about eight miles north 36° east from the Iron Works." * Its height he gives as "3,010 feet, being 2,416 feet above the ground in front of the furnace of the Iron Works." † He says again: "I was disappointed when I got to the summit to find it composed of the same slate formation that I had been on so long." After a few lines more he adds: "To the northwest are several mountains, the highest of which is called 'White Cap,' on account of its naked white summit, which, as a hunter informed me, is composed of granite. It is about eight or ten miles from Saddle Rock, and is probably near the southwest limit of the Katahdin granite region." ‡

This report of a "hunter," and Dr. Jackson's false statement, grounded on hearsay, that Joe Merry Mountain is made up of granite, constituted Mr. Houghton's only warrant for considering the granite district to extend beyond the Pemadumcook chain of lakes, and so far south as the northern line of the township next north of Brownsville, as is represented upon the geological map. Furthermore, the fact that, in the whole forty miles of the route between Ktaadn and the imaginary southern line of the district, granite has been found coming to the surface, over exceedingly narrow areas, in *five* localities, — viz. at the third, fourth, and fifth falls, near the outlet of North Twin Lake, and at the Upper Joe Merry Lake, — furnishes a very slender basis for belief in the existence of a continuous granite area south of Ktaadn.

Suppose we concede to be made up of granite the cliffs seen by Mr. Hodge and myself on the hill, or hills, west of Katepskonegan Dead-water, and apparently identified by him as granite through a distant view gained as he passed up the river in his boat; and White Cap, *reported* to consist of granite by one whom we do not know to have learned its character from personal examination. With these additions we have data still entirely insufficient to justify the conclusion that has been drawn from them.

The sudden appearance, and as sudden disappearance, of granite in districts covered by stratified rocks, are characteristic of Central Maine. The granite not uncommonly occurs as isolated hills separated by a greater or less extent — sometimes by a score of miles — of unbroken strata. The same reasoning that would make the district south of Ktaadn a continuous granite area, would apply as well to others known to be underlaid by strata through which granite shows itself in detached hills or ridges.

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* Prel. Rep. Nat. Hist. and Geol. of Maine, p. 430.

† Ibid., p. 430.

‡ Ibid., p. 431.

The case of Augusta, situated near, but not at, the southern border of the region of slates and schists, is instructive in this connection. The conclusion which even a geologist looking over that vicinity in haste might feel to be the natural inference from obvious and abundant data, would nevertheless be a wholly false one. An outline of the case only can here be given. Augusta city is built on both sides of Kennebec River, upon well-developed terraces which form the sides of a valley that has there been excavated to the depth of 300 feet below the level of the adjacent country. The width of the valley east and west, from summit to summit, is a little over one mile in a straight line, and midway runs the river in a course somewhat west of south. The terraces and summits on either side are composed of drift deposits, so thick that the deepest wells nowhere reach solid rock; and four sharp ravines, that on the western side cut the terraces down to the level of the river at their mouths, have bottoms and sides of drift, as has the river bed, except at two points. The highest part of the western summit is a "granite" ledge which rises in a knob some thirty feet above the rest of the summit and the general level of the country. Its top has an area of not more than one or two acres, and falls off rapidly on the north, east, and southeast beneath the enveloping drift. A mile south of this point, and half a mile southwest from the State House, is a broad hill, about 400 feet in height above the river. On its southwest side, which lies in Hallowell, are the quarries that furnish the well-known "Hallowell granite." The hill throughout is a solid mass of the same material. In riding out of town two miles to the west, northwest, or northeast, one comes upon several "granite" quarries in each direction. In view of the foregoing facts, a visitor would feel himself justified, if no further examination were made, to pronounce "granite" to be the underlying rock of the vicinity. But should he notice just across the railway track from the station, at the foot of the second terrace, forty feet above the river and 200 feet from it, an exposure of rock now mostly hidden by a granite bank-wall, he would find it to consist of hardened, upturned schist; and in the drought of summer he would see in the river bed, for a few rods above and below the railway bridge, ledges of the same schist.

Across the deep, narrow valley of a tributary to the Kennebec, above half a mile in an air-line northeast from the granite knob before mentioned, and at the northern limit of the city proper, rises more than 300 feet above the river what was formerly known as the Andros Hill, the upper part of the so-called Cushnoc Heights. On the southeastern slope of its upper hundred feet, on nearly the same level with the road, but on the opposite side of that part of the hill, and so hidden from the view of the passer-by, is an abandoned quarry of mica schist. Here, too, the rock plunges off on the south, east, and west beneath an unknown depth of drift.*

Finally, should the observer examine, for the four miles that intervene between Andros Hill and the northern line of the township of Augusta, the very few exposures of rock in place that occur along the river road on the west side of the Kennebec, and upon the farms crossed by the road, he would find in every case schist, and that only. Upon the corresponding road east of the river, only schist is found for the whole six miles of its length across the township. It is evident, then, that the underlying rock of Augusta is the upturned schist, which becomes at Waterville, eighteen miles north of Augusta, the almost vertically placed Taconic or Lower Silurian slate that stretches to Moosehead Lake on the north, and easterly to and beyond the city of St. John, N. B.

In the great denudation which this extensive region has undergone, the more resisting granites† of Kennebec County have been left projecting as hills above the softer schists, which, worn down to lower levels, have been covered with deposits of drift, frequently of great thickness. For miles these lower grounds and the hills also may be traversed without meeting any indication of the nature of the underlying rock. Thus, upon the road along the western side of the Kennebec, between Andros

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* Half a mile above the bridge, at the foot of Cushnoc Heights, is the Kennebec Dam. In 1839 a freshet swept away seven acres of land at the west end of the dam, and cut a new channel for the river 500 feet in width, the floor of which, when the waters abated, was found to be a transverse ridge of well-marked mica schist. In extending the dam across the new channel, the rock thus laid bare was soon after hidden again from view.

† The so-called granite of Hallowell and Augusta was termed by Jackson "granite gneiss" (First Rep. Geol. of Maine, p. 83), and is declared by Dr. T. Sterry Hunt to be "true gneiss" (Am. Jour. Sci., [3.] I. p. 85). But is the sudden transition, in so many places within a small area, from crystalline rock to distinct schists, compatible with the idea that the former is a metamorphosed portion of the latter? Are not the relations of the two more consistent with the hypothesis that the "gneiss" is in reality eruptive granite, which in its passage through the strata has changed the original slates into hardened schists?

Hill in Augusta and Waterville, I remember but five small spots where rock *in situ* rises to the surface. Upon the adjoining farms a few others may be observed. All are little patches of outcropping strata. Going northward from Augusta, wherever the strata are harder than usual they rise into hills. At Waterville, while fissile slates occupy the low grounds, they lose the slaty structure and pass into hard schists in several high hills, one of which presents a bold, precipitous face. The numerical proportion of such hills increases farther north, till, south and east of Moosehead Lake, so far as examination has been made, hills and mountains of schist far outnumber those composed of granite. Isolated granite hills occasionally rise in districts of slates and schists, but nowhere is anything to be found that can be termed a granite district. Judging from the foregoing facts and instances, we must think, until stronger proof to the contrary is produced than at present appears, that the country south of Ktaadn, to and beyond the Joe Merry Lakes, is part of the great region of stratified rocks which surrounds it on all sides. On such an hypothesis, the presence of Joe Merry Mountain where it is — a mass of schist — is comprehensible; but how shall it be accounted for if supposed to rise out of a granite district?

On arriving at the mouth of the stream where the trail from the river to the summit of Ktaadn begins, it had been my purpose, before making the ascent of the mountain, to run up the Penobscot twelve miles farther, to Ripogenus Portage, upon which occurs the border line between the granite and the stratified rocks in that direction. But lack of water in the river, and its obstruction by great gatherings of logs, formidable enough below and known to be worse above, made further boating impracticable. The Ripogenus trip was therefore unwillingly relinquished.

Of the northwestern portion of the so-called granite district, I can speak, then, only from notes and recollections of a canoe excursion made in 1871 from Moosehead Lake downward. They enable me to say, however, that the river's course, from the Ripogenus Gorge to Sourdnahunk Falls, lies chiefly among hills. Those on the north skirt closely the left bank of the river, and are foot-hills of the Sourdnahunk Mountains, which are a little beyond. The hills are frequently precipitous, presenting a frontage of granite cliffs. Except at the Ambajemackomus Falls, where the river plunges eight or ten feet over a shelf of granite, I have no distinct remembrance of ledges in the channel, which is thickly strewn with granite bowlders. But the character of the heights adjacent upon the left leaves no room for doubt that, between the limits specified, the Penobscot flows over underlying granite, superficial or drift-covered.

Mount Ktaadn, as we shall see, is composed wholly of granite, and its relation to the Sourdnahunk Mountains, which extend from Ktaadn westerly ten miles, is such that it and they must be regarded as parts of one continuous range. It cannot be doubted, therefore, that a Ktaadn "granite area" exists, having for its length that of this range, and including on its southern side the channel of the Penobscot, at least so far down as Sourdnahunk Falls, which are three miles above the mouth of Aboljacarmegus Stream. These statements are confirmed by the few observations upon this part of the river which the Geological Reports record.

The floor of the Great Basin of Ktaadn has an elevation of 2,900 feet above the sea. As one goes outward from it by the present route to the East Branch of the Penobscot, better styled the Mattagamon River, he skirts along the northern foot of the abrupt portion of the eastern mountain. On leaving that, he quits the last trace of rock *in situ*, which nowhere reappears in the descent of more than 2,400 feet made along the twenty-three miles of way to the crossing of the Mattagamon at the Hunt Place. There is abundant testimony that ledges do not come to the surface on the old Keep Path, which diverges from the present route at Ktaadn Lake and runs seven miles to the foot of the East Slide. It is certain, then, that on the east side of Ktaadn granite has not been discovered upon the gradual lower slopes of the mountain, which make up nearly half of its whole height. It is certain, too, that just beyond the western or Sourdnahunk end of the range, the granite disappears beneath the surface. To the south of the Sourdnahunk Mountains, as we have seen, granite without doubt makes up the river channel; but the aspect of the low country to the south warrants the supposition that granite as a superficial rock extends in that direction not far beyond the Penobscot. It seems, therefore, in the highest degree probable, that the Ktaadn "granite area" includes little but the mountains themselves, and that, nowhere extending far out from the foot of the range, it does not, in some parts, embrace even the lowest slopes.

Mount Ktaadn.

The low country south of Ktaadn has an average elevation of not more than 550 feet above the sea. From it rises the mountain by moderate gradations to less than half its altitude, or about 2,200 feet on the south side, but the upper portion, rearing itself 3,000 feet higher, is bounded by declivities of great abruptness.

A brief description, illustrated by the accompanying heliotype of a model which represents the upper three thousand feet of the mountain, will render intelligible subsequent references to the general features of Ktaadn.

The crest that bears the highest peaks is bent like a deep crescent, opening north, and enclosing the Great Basin. At the centre of the crescent are the two chief peaks, which differ in altitude less than twenty feet, and are not more than a third of a mile apart. Directly beneath the East Peak, shoots off to the southeast the longest of all the spurs, which, narrow above, widens greatly towards its foot. Beyond the peaks, the eastern horn of the crescent includes a thin, serrated crest, and forms at its tip, first, the little tower-like peak known as the Chimney, and then, across a narrow, square-cut notch, the peak of Pamola,* named from the Indians' demon of the mountain. It is known to many only as First Peak, so styled because it was the first summit reached by tourists who followed the original eastern route to the mountain. Pamola has a regularly convex, wide northern face, that runs down with a precipitous foot to the level of the basin floor, nearly 2,300 feet below the highest peak. Eastward from Pamola projects a narrow, sharp-ridged spur, the "Horseback," — an unfortunate name as here applied, since in other cases it invariably means, in Maine, a kame, with which this buttress of solid rock has nothing in common. Towards its extremity, the "Horseback" forks, and sends off to the northeast a lower, flat-backed spur, while on its southern flank is the East Slide, — the smaller of the two great slides that are among the peculiar features of Ktaadn.

Against the western horn of the crescent abuts the Table Land, an almost absolutely plane surface, inclined to the northwest at an angle of from five to seven degrees, and having a length of a mile and a half, and an area of more than five hundred acres. The centre of this plateau is a few hundred feet lower than the highest peak, which has an elevation of 5,215 feet, as determined by Prof. Fernald. Half a mile below the middle point of the sharp brow that bounds the Table Land on the south is the head of the Southwest Slide. This slide is the track of an enormous avalanche, which, in 1816,* swept over a course of not less than four miles in length. A mile or more of the lower part is now wholly grown up to forest, but the upper part, for a mile and three fourths, is still covered with loose fragments of rock and gravel, upon which vegetation has not encroached, except along the sides. The East Slide is less than a mile long.

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* The name as given by Jackson and those who have followed him is *Pomola.* I have chosen the form *Pamola* on the authority of Rev. Eugene Vetromile ("The Abnakis and their History," pp. 63–67), for many years Catholic missionary among the Indians of Maine and New Brunswick. Dr. De Laski, in a paper to be referred to farther on, applies the name incorrectly to the "apex of Katahdin."

The Table Land narrows on the west, and sends off a sharp-ridged spur that curves to the southwest. From West Peak there is a descent northward and westward, into which the Table Land merges, down to the level of 4,250 feet, — the lowest part of the central mountain, termed the Saddle. Northward from this rises rather gradually a rounded summit 450 feet higher than the Saddle, or 4,700 feet above the sea, and 515 feet lower than West Peak. Three fourths of a mile farther northeast is a second summit, similar to the first, but slightly lower, the two being separated by a moderate depression of the ridge. A half-mile farther, in the same direction, follows a third rounded summit, perhaps seventy-five feet lower than the first. From the first and second northern summits run eastward two sharp and narrow spurs, which include the North Basin, so named to distinguish it from the Great or South Basin. The northern face of this smaller basin is made up of cliffs for the most part nearly vertical. From the second summit runs west another long and flat-topped spur.*

Beyond the Saddle, the mountain stretches some seven miles to the northeast, and terminates in a knot of lower spurs, having in the main flattish tops and precipitous sides.

The Great Basin, in its whole extent, forms an amphitheatre, which, seen from above, strongly resembles an old volcanic crater. In the absence of trigonometrical measurements, its dimensions cannot be accurately stated ; but they may be approximately given as from summit to summit east and west two and a half miles, by a mile and a half from north to south. Its most precipitous part, the southern lobe, measures from its head to the Basin Pond about three fourths of a mile, and its width is nearly the same. The smaller North Basin approaches in shape the capital letter U, and is about a mile and a half long and half as wide, fronting a little south of east. The larger basin has a narrow gateway opening to the northeast.

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* Williamson's History of Maine, Vol. I. p. 90.

† In photographing the model, light fell upon the western spurs exactly in the direction of their length. Flooded thus with light, these parts have not enough of shade to render them distinct.

The wall of the Great Basin rises highest above its floor on the south, becoming gradually lower on the east and west sides. The height of West Peak above the Basin Pond, as determined by the mean of six pairs of simultaneous observations taken with a Green's mountain barometer at the level of the pond, and with an aneroid upon the peak, was found to be 2,287 feet, which is the depth of the basin, measured downward from the top of the same peak. Its walls on the south and east are so steep that they have never been climbed, except at one or two points, as an act of foolhardy daring. The height of Pamola above the little pond, as estimated from a single pair of simultaneous observations, is 1,891 feet, or 396 feet less than that of the highest peak.

It is within the walls of the Great Basin, and upon their summits, that the geology of Ktaadn can best be studied. The whole mountain, from the lowest point where rock in place has been discovered, is composed of granite. Of this, five specimens, numbered 3, 5, 23, 25, and 57, have been examined by the lithologist of the Museum, Dr. Wadsworth, whose notes upon them are here given. In a general description of the mountain, it may be said that it is made up of two varieties of granite, the gray and the red. To the first variety specimen 3 belongs; to the last, belong 23, 25, and 57; 5 being in a manner intermediate between 3, on the one hand, and 23, 25, and 57, on the other.

Dr. Wadsworth's Notes.

No. 3. — A gray granite, composed of feldspar, quartz, and biotite. The feldspar is of two kinds: a grayish-white one, with a pinkish tinge, is the most abundant, while subordinate to it occurs a milk-white striated feldspar. The powder of the rock is magnetic. Under the microscope the thin section is seen to be composed of orthoclase and plagioclase, quartz, biotite, and magnetite. The orthoclase is much decomposed and cloudy, showing only feeble polarization. The plagioclase, in general, is much less altered, and shows its triclinic character well in polarized light. Some of the crystals, however, show the characteristic banding only in places, principally at the ends and sides of the crystals, while in the more altered portions the twinned structure is rarely seen. This alteration renders it very uncertain that the supposed orthoclase is really all so; and we feel that this has been a fruitful source of error in the microscopic examination of rocks. The quartz contains numerous fluid inclusions, moving bubbles being seen in them; it also contains trichites and minute crystals. These crystals are probably apatite and zircon. Some apatite crystals were seen in the feldspar.

No. 5. — A pinkish gray granite of the same composition as No. 3, the difference in color being due to the deeper color of the feldspar. It shows in the thin section similar characters to No. 3, except that the feldspars are more decomposed, and therefore less plagioclase could be seen, while the quartz contains more abundant trichites.

No. 23. — A brownish red granite of similar composition with the preceding. Feldspars colored pink and greenish white. Calcite and a greenish talcose mineral occur as alteration products. In the thin section the feldspar is seen to be greatly altered, and but very little of it shows any trace of triclinic characters. The biotite is partly decomposed, and has a greenish color. The general character of the rock is slightly more basic than the two preceding, but we do not consider that there is enough difference to lead us to regard them as distinct. We should rather regard them as parts of the same formation.

No. 25. — In this specimen the greenish feldspar predominates over the pink. The rock shows abundant signs of weathering, containing numerous cavities formed by the decomposition of its ferruginous minerals, and now partially filled with hydrous oxide of iron. Under the microscope this is seen to be the most decomposed of any of the specimens, the biotite being almost wholly changed, and almost no plagioclase being recognizable. Many parts of the rock are filled with viridite. The quartz, besides its numerous fluid inclusions, contains dodecahedral quartz crystals of the same character as those so commonly seen in the quartz of rhyolite. This rock is similar to No. 23. We should regard these rocks as eruptive, but we are well aware that others would claim that the microscopic characters are those which belong to metamorphosed sedimentary rocks.

No. 57. — This rock is seen in the hand specimen to be composed of flesh-red orthoclase, pale greenish white feldspar, somewhat decomposed, together with altered biotite and quartz. The biotite has been changed to a chloritic material. The minerals give to the rock a greenish red color. It is more coarsely crystalline than the other specimens from Mt. Ktaadn, and in its general facies is somewhat unlike specimens 3, 5, and 25.

The lower two thirds of the basin walls are composed of the gray granite, which is similar in composition and appearance to that of the lower slopes of the mountain on the south side, and to that of Katepskonegan Falls, except that the rock of the localities last indicated contains only the white feldspar. The upper third of the walls consists chiefly of the red variety (5), the modifications represented by Nos. 23, 25, and 57 being found only upon the very highest parts of the mountain, — the East and West peaks, the serrated crest, and the ridges that connect those portions. The rock represented by the last three numbers is throughout so badly decomposed that only once was a specimen (57) obtained tolerably sound and firm under the hammer. The rock represented by No. 5 is oftenest, but not always, found in a crumbling condition; while the gray variety (3) is generally comparatively solid, but occurs in a few places in the last stages of disintegration.

From the shores of the Basin Pond, where an unobstructed view is to be had of the whole height of the walls, the granite, up to two thirds the height of the eastern side, or about the upper limit of the gray variety, is seen to be arranged in concentric sheets, that dip west at an angle varying from 45° to 60°. On the southern wall the same concentric arrangement prevails, the layers dipping north, often at angles higher than 60°. Above the part that lies in concentric sheets is the red granite, which divides, on weathering, into blocks more or less regular in form. Near the head of a torrent that comes down from the Saddle, in two instances the red variety (5) lies in blocks, with forms so definite as strongly to resemble courses of cyclopean, but crumbling masonry. At the foot of these "castles" the rock is so friable as to fall into gravel under the tread.

What has been said of the occurrence of the red and gray granites, at different elevations, does not mean that they are separated from each other by any well-defined horizontal plane. They are undoubtedly parts of one and the same formation, and, as in the quarries of Quincy and Cape Ann a variety of rock having one color passes into a variety of another color so gradually that the separation cannot be said to take place along any line, or plane, so at Ktaadn the red and gray granites merge into each other in the same way, and at various levels. Yet it is substantially true that the lower two thirds of the basin walls, and probably the whole of the mountain mass below the level of the basin floor, consist of the gray, and the upper 700 feet of the red granite.

As has been remarked already, the granite of Ktaadn is singularly free from dikes and veins. During the explorations made both in 1879 and 1880, not a dike or vein was discovered, either in the fixed or loose rocks of the mountain. We have seen that the same was true, with but two exceptions, of the ledges and bowlders that were observed upon the Penobscot. The absence of these characteristics of older rocks will be held to indicate that the granite of Ktaadn and its vicinity is of comparatively recent origin.

The only considerable departure from the normal granitic type is the occurrence of very numerous inclusions which resemble imbedded fragments of foreign rock. Like patches are common in most granites, but I have never known elsewhere so many as the Ktaadn granite presents. Upon the talus beneath the east wall of the basin a small block of red granite was observed which contained five visible inclusions, varying from two and a half to seven inches in diameter. In respect to numbers, this was an exceptional case, but single inclusions met the eye at every turn. Of specimens collected in the basin, some have their outlines sharply defined, but others merge gradually into the enclosing granite. As usual, they are finer in grain, and of darker color, than the surrounding rock, being commonly of a deep gray, but sometimes lighter from the presence of imbedded crystals of white feldspar. Upon the Southwest and East Slides a few inclusions were found of another character. Of these, one was brought away from each locality, — the best of its kind. They seem to be fragments of almost black mica schist, are angular on all sides, are separated from the granite by lines perfectly distinct, and were selected as pieces of foreign rock which had been caught up by the granite and included within its mass.

Inclusions in granite have long attracted attention, but have not been the subject of much investigation. A clear and extended discussion of their nature, with figures of specimens and a record of analyses, may be found in a paper, by J. Arthur Phillips, entitled "On Concretionary Patches and Fragments of other Rocks contained in Granite." * In his "General Conclusions," the author makes the following statement : "The inclusions contained in granite are of two distinct kinds. Those of the first class [which are spoken of throughout the article as concretionary, though not exhibiting a concentric structure] are the result of an abnormal arrangement of the minerals constituting the granite itself, while those belonging to the second represent fragments of other rocks enclosed within its mass." (p. 19.) Most of the patches observed in the basin must be assigned to the first class, while the specimens brought from the slides seem clearly to belong to the second.

The forms which the several parts of the mountain now present, and the condition of their surfaces, are largely due to the original structure and mode of weathering that characterize the rocks. As the highly inclined concentric sheets in the basin walls break away, and fall upon the talus below, other faces of equal inclination are exposed ; while the red granite of the higher parts, deprived of support, in turn gives way, and thus the steepness of the walls is maintained. Similar steep faces, due to the concentric structure of the granite, abound upon other parts of the mountain, as on the flanks of several spurs, and about the base at various points.

The crest (a feature unique among Eastern mountains) that occupies most of the space between East Peak and the Chimney owes its form and

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* Quar. Jour. Geol. Soc. of London, Vol. XXXVI. pp. 1–22, February, 1880.

preservation to the circumstance that the modified red granite which makes it up divides in weathering into plates, which, when undisturbed, stand vertically on edge. They vary in thickness from an inch, or less, to upwards of a foot. Where their trend is in the same direction as the ridge, there, as they have become loosened, and have fallen over the cliffs on either side, the plates still left firm in place constitute a narrow crest. It is surmounted by a serrated edge, and, as one follows it for the fourth of a mile, alternately ascending steep projecting points, and descending into jagged notches between, he must again and again walk along a mere blade of rock from one to two feet wide, having upon one side the yawning gulf of the basin, and on the other cliffs too steep for climbing.

From the crest southwest to East Peak, and between that and West Peak, the rock plates stand crosswise of the ridge at various angles, and there, as they have been loosened by frost, falling more or less out of perpendicular, they still remain. Thus the blade-like form is lost, and the ridge is somewhat wider, though still narrow. Bristling with oblique, projecting plates covered with black lichens, these parts present a savage and chaotic desolation that is probably without a parallel in Eastern North America.

The very diverse conditions of surface upon the other summits — hardly their forms — may be traced sometimes to variations in the jointing of the constituent rock, but oftener to simple difference in firmness. Thus, parts made up of the more friable red granite (other than those modifications of it, represented by specimens 23, 25, and 57, that divide into thin plates, and are confined to the highest summits only) are covered with small-sized fragments, rounded by decay. These at times assume, over wide spaces, the size, and almost the arrangement, of cobble paving-stones, and in a few places the aspect of gravelled areas. Such are seen chiefly on the northern summits.

Again, the middle of the northward slope, between the Table Land and the Saddle, is piled with blocks of the firmer red granite, riven from the mass beneath, of size so great as to render travel over them extremely difficult. The Table Land is in parts smoothed by a covering of wholly disintegrated material, but in general is strewn with tabular blocks that increase upwards toward West Peak in size and number. The half-mile between the head of the great Southwest Slide and the brow above is literally a heap of huge blocks, constituting a slope that varies from 36° below to 47° above.

The slopes south from the two chief peaks are covered with loose, angular, often tabular fragments, as far down as to the tree line, which is everywhere upon the mountain very low, leaving an unusual amount of naked rock above. These slopes present much the same appearance as does the top of Mt. Washington southward from the Summit House toward the Lake of the Clouds, except that on Ktaadn the blocks are larger, and the slopes much more abrupt.

All the summits so far described are bare of vegetable growth larger than lichens, or shrubs like the mountain cranberry, almost as diminutive as mosses, and are therefore open to close inspection. The whole rock surface has been so shattered that only on faces of cliffs too steep to allow the accumulation of detritus is rock in place to be found. To the east spur of Pamola, the "Horseback," the last statement will not apply. This narrow ridge may be said, in a great measure, to have *shed* its ruins as they have been formed. Consequently, the spur, over all its upper part, exhibits along the ridge abundant granite in place. Here, of course, the present surface is of recent origin.

Except a few paragraphs in the brief accounts of hurried visits made to Ktaadn by Dr. Jackson and Prof. Hitchcock, contained in the Maine Geological Reports, a brief article by the late Dr. John De Laski,* of Vinalhaven, and a reference of three lines in the second and third editions of Dana's Manual of Geology, based upon an erroneous statement of De Laski's, I recall nothing in print that specially relates to glaciation in connection with Ktaadn. Prof. Fernald's observations for the latitude of the highest peak make it to be 45° 53′ 40″. The parallel of 46°, therefore, crosses the northern base of the mountain. Farther north than Mt. Washington by over one degree and a half, and, according to the computation of Mr. W. H. Pickering, 161 miles distant from it in a straight line, and of New England mountains inferior in altitude only to the highest summits of the Washington group, Ktaadn becomes of so much interest that, but for the inaccessible nature of the region, the mountain and its vicinity would long since have been thoroughly explored for testimony upon the question of a great northern ice-sheet, and the existence of former local glaciers.

As might be expected, upon summits changed from the original condition to the extent that has been indicated, days of search failed to discover any signs of glacial striæ, or polish. Examination for them was made also, without result, on the lower slopes: first, where the trail from the Aboljacarmegus Stream, about a mile from its beginning, crosses a succession of bare granite areas, and at the next exposure of granite in the course of the trail, which is just at the foot of the present terminus of the Southwest Slide. At both localities the rock is of the coarse gray variety that is exposed at the third and fourth falls, and is destitute of glacial markings. The surface is honeycombed by decay, which, at the lower station, has gone so far that it was there impossible to break out, with a heavy hammer, specimens which at all approached a sound condition.

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* Am. Jour. Sci., [3.] III. pp. 27–31, 1872.

The only rock in place to be seen upon the Southwest Slide occurs two thirds the way up from its foot, at an elevation of about 3,500 feet. It is a fine-grained, dark gray granite, approaching in appearance some of the inclusions that are found in the basin, and well adapted to resist decomposition. It lies, as at the stations below, in concentric sheets,* which have here an inclination of about 30°, and is smooth, hard, and free from all indications of decay; but not a scratch or other sign of glaciation appears upon it. It is a small area, only seventy-five feet along the slope, and perhaps a third as wide, and disappears above, below, and at the sides, under the débris of the slide, beyond the slanting face of which the ledge scarcely projects. If it was first uncovered, in recent times, by the descent of the avalanche of 1816, as from the surroundings seems not improbable, the absence here of grooves and striæ is significant as respects the glaciation of the higher parts of the mountain.

If evidence of glaciation upon the summits of Ktaadn exists, it must be other than that to be derived from smoothed and striated surfaces. It will be maintained by many that such evidence is supplied by the flat tops of the Table Land, and of several of the spurs, and by the well-rounded northern summits and faces. To this it may be objected that table-topped mountains are not wanting in regions where neither drift nor other indications of glaciation have been recognized. The statement, however, is open to the rejoinder that, in such cases, the shape may be rationally accounted for by obvious peculiarities of structure, as is the typical instance of Table Mountain, near the Cape of Good Hope, which is a mass of granite capped by horizontal beds of sandstone. The prevalence of steep faces upon the sides of Ktaadn, as already remarked, is to be ascribed ultimately to the high inclination of the concentric sheets of granite; but there is absolutely nothing in the rock structure that will help to account for the existence of a great plane surface of above five hundred acres, like that of the Table Land. The supposition that it is the work of moving ice is a natural and rational one, provided the weight of proof in support of such an hypothesis is greater than that of proof antagonistic with it. But to cite testimony for, or against, any particular theory, does not come within the scope of a brief paper like this, whose chief purpose is the presentation of facts.

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* My observation of Maine granites in general, and especially at Mt. Ktaadn, forces me to the conclusion that the concentric lamination of granite is due to causes connected with the original structure of the rock, and not, as has been maintained by Professors Shaler and Hunt, to superficial variations of temperature during the changes of the seasons. It would seem, then, to be putting terms in their logical order to speak of the conformity of present surfaces to the inclination of the granite sheets, rather than of the lamination as conformable with superficial features.

Material interesting from its relation to the transportation of drift, whatever may have been the agent that moved it from the north, is not wanting upon Ktaadn. The two slides furnish the chief amount of such material. The present Southwest Slide proper — the loose slide — begins a little above the point where the old avalanche started, a full half-mile below the brow of the Table Land, and terminates at the foot of the most abrupt portion of the mountain. The length between the points indicated, as estimated after repeated ascents and descents, is one mile and three fourths. The width at the bottom is about 100 feet, narrowing very slowly upwards. The difference of elevation between the top and bottom is 1,774 feet, — the mean of two observations. In its course the slide exhibits several terraces, at places doubtless where it conforms to the varying slope of the solid surface of rock over which it passes. The inclination, therefore, is variable. As tested with a clinometer at several points, it appears to be as follows. From the foot to the "Green Island,"* a small bush-grown patch upon the surface of the slide, and 985 feet (mean of two observations) higher than its foot, the inclination of the slopes between the terraces varies upwards from 24° to 28°; thence to the top it is 31°. The average inclination of the rock-piled surface, from the head of the slide to the brow of the Table Land, is 35°, but the last seven minutes' climb is upon a slope of 47°. Along the lower two thirds of the slide, drift is distributed in considerable quantity, but on the upper third it is rarely seen, and disappears entirely before the top is reached.

The East Slide is less than a mile long, and is one continuous slope, uninterrupted by terraces like those of the Southwest Slide. The inclination of the lower half was found to be 25°; of the next fourth, 28°; of the upper fourth, 30°. Its foot lies about 200 feet lower than the level of the Basin Pond, and its head is 1,000 feet above the same level, making the elevation of the head above the foot about 1,200 feet. It had its origin in an avalanche which is said to have descended between 1820 and 1830. The two slides will in time disappear, as others before them doubtless have, by the slow encroachment of shrubby growth from the bottom and sides, now seen to be in progress. On the East Slide much less drift is found than on the other. Outside of the slides, I have never found drift upon the flanks of the mountain; but it reappears higher up, in very small amount on the Table Land, but principally upon the northern summits, sparsely strewn among the broken granite that covers them. Neither on slides nor summits is the drift ever found in large bowlders, but always as fragments of moderate size. On the Southwest Slide a *few* masses were seen as heavy as a hundred pounds each, but in general — always upon the East Slide — the pieces ran from a few ounces up to twenty pounds in weight. They were chiefly fragments of slates and sandstones, identical with the strata of the country north and west, mingled with pieces of metamorphic and trappean rocks, such as occur in place for a few miles beyond the Ripogenus Carry.

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* A landmark conspicuous for miles down the Penobscot, and recognizable in photographs.

The fragments of stratified rocks on the Southwest Slide very generally include fossil shells, mainly Brachiopods, and always impressions or interior casts. Owing to the small size of the enclosing masses, — due to the fissile structure of the rocks, — the fossils ordinarily are much decayed, but occasional specimens are obtained in fine condition. Among the scanty drift upon the upper third of the Southwest Slide, I have never seen a fossil-bearing stone. And upon those parts of the summits where drift was found, only once was a fossil met with, — a solitary Brachiopod impression on a ten-pound piece of sandstone, picked up on the slope northward from West Peak to the Saddle, about 600 feet below the top of the peak, or at an elevation of about 4,615 feet above the sea. This is by far the highest point at which fossiliferous rocks have yet been found upon Ktaadn.*

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* Dr. De Laski's statement of the height (4,385 feet) at which he found fossils, "well up toward the 'Horseback' ridge" (Am. Jour. Sci., [3.] III. p. 27), and which is quoted by Prof. Dana in his Manual of Geology (editions 2d and 3d), is founded upon a wrong estimate of the altitude of the mountain. He adopted the one current for some years before Prof. Fernald's remeasurement of the elevation, which he made to be 5,215 feet. Now the elevation of the "Horseback" ridge, at a point directly up from the head of the East Slide, — Dr. De Laski's route, — we make 1,181 feet above Basin Pond, while that of the summit of Ktaadn is 2,287 feet above the same level. The difference 2,287 — 1,181 = 1,106 feet, the difference of elevation between the "Horseback" ridge, at the point named, and

For a purpose presently to appear, it is pertinent here to introduce an observation made by Prof. Hitchcock in the valley of Avalanche Brook, a stream that, starting from the gorge between the Chimney and Pamola, abruptly terminates the East Slide by sweeping away the detritus at its foot, which the brook passes nearly at right angles. This "valley," where we saw it, is only a rocky channel, heaped with bowlders of all sizes. In the dry season there runs, half hidden among the rocks, a rivulet, which, in times of flood, becomes a furious torrent, and fills the banks. Says Hitchcock: "We ascended the valley of Avalanche Brook on the south side of the mountain, and . . . . found an immense number of bowlders of Oriskany sandstone, many of them highly fossiliferous. . . . . We found none of these bowlders higher than the foot of the slide, although others have found them a few hundred feet higher." *

Among the other drift met with upon the slides, we found smoothed and striated stones, scratched uniformly in the direction of their length, and rounded at the angles. They are the first of their kind that have been reported from Ktaadn. The best were as fine examples of what are considered typical glaciated fragments as any that are figured as such in geological works. The largest, weighing from ten to fifteen pounds, were more deeply scored than the smaller; but being too heavy to be borne many miles in our packs, they were unwillingly left behind, and others of less weight were selected as specimens. Of two that were brought away, one is a piece of hard trap rock (determined by Dr. Wadsworth to be diabase) five inches long by two and a half at its widest part, and weighing twenty ounces. The other is a thin piece of fine-grained argillaceous sandstone, seven inches by three and a fourth, split from some larger stone that was not discovered. Of such striated fragments not more than a dozen in all were found upon both slides. They were rare exceptions among drift that showed no striæ. According to the testimony of books, and of several persons familiar with glacial phenomena from their own observation, the specimens agree precisely in character with stones worn at their angles, and grooved on their faces, under the ice of existing glaciers. It is of course impossible to conceive them to have been shaped and grooved simply by the friction they would have suffered in descending by gravity down the slide among the other débris.

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the summit; and 5,215 — 1,106 = 4,109 feet, the height of the given point of the ridge above sea level. It was *below* this point, it will be observed, that De Laski found his "upper fossils."

* Prelim. Rep. Nat. Hist. and Geol. of Maine, p. 395.

All the facts in the case serve to indicate that the non-granitic material found upon the mountain is a portion of the so-called "northern drift," with the fact of whose distribution — not the manner — we are here concerned. But we may and must suppose that in the distribution the sides and summits of Ktaadn, as far up at least as 4,600 feet, received deposits of drift more or less in quantity. Through the action of gravitation the slopes have become loaded with fragments of granite that have been wedged from its mass by frost. Ktaadn has thus been buried under its own ruins, and beneath these ruins has been hidden the drift that was deposited when the mountain was comparatively intact. The avalanches which have produced the slides have brought to light along their course the covered drift. Near the starting-point of the descent, where the movement was superficial, little or none of the hidden material has been unearthed; but farther down, where the avalanche ploughed deep, more was brought to the surface. The shorter East Slide, therefore, which is superficial in comparison with the other, shows far less drift than does the Southwest Slide; while Avalanche Brook, which flows over the steepest of the lower slopes, reveals in its deep channel more of drift than has elsewhere yet been found upon the whole mountain. There is reason to think that the bed of another stream, that runs on the north side of the East Spur, will, if followed up, yield like testimony.

But while proofs of the former presence of an ice sheet upon Ktaadn are so scanty and questionable, seeming indications of local glaciation are not wanting. The location and surroundings of three little ponds, that lie just without the mouths of the basins, are at least significant. Their waters are retained in place by low, irregular ridges, situated just where terminal moraines of glaciers issuing from the basins would naturally occur. Those that hem in the second and third ponds, counting from the outlet of the chain, on the supposition that they are moraines, must have been deposited by glaciers that moved down from the North Basin. The ridges that hold the first pond, and separate it from the second, would seem to have been supplied by a glacier from the South Basin. Entirely satisfactory determination of the nature of these ridges is impossible while they are, as at present, completely masked by dense thickets; but should fire hereafter lay them bare, opportunity will be afforded for thorough examination before a new growth springs up.

The outlet of the first or lower pond is cut to the depth of about twelve feet, through a ridge of débris that appears to be the continuation of the one which runs along the eastern margin of the same pond; and there can be but little doubt that the loose structure observed at the outlet prevails through the whole length of the retaining ridge. But as a running stream can speedily change stones over which it passes from irregular and angular forms to rounded and smoothed water-worn pebbles, such as now cover the surface at the outlet, no proof that the material of the ridge has the characters of a moraine deposit is attainable till an amount of digging is performed for which we had neither time nor tools.

Half a mile from the point last named is a little bog, fifty by one hundred feet in extent, represented in the heliotype as a faintly drawn pond. Going outward from the basin, one steps from the surface of the bog directly upon the foot of a narrow ridge, which rises abruptly to the height of twenty feet, and as abruptly falls off on the opposite side to a level much lower than that of the bog. Its relations to the adjacent heights favor the view that it is the terminal moraine of a glacier that came down a wide depression of the mountain side, between Pamola, the "Horseback," and its flat-topped branch. The hollow is widest and steepest above, and would constitute a promising gathering ground for a glacier. So far as could be ascertained, without extensive digging, the elevation apparently consists of loose material, which might be regarded as moraine débris.

Higher up in the same hollow, and nearly at the end of the flat-topped spur, is another diminutive pond, nestled behind what looks from a distance like the remnant of a moraine deposited later than the one below, and of which the greater part has been removed by denudation. These ponds will forcibly remind one who is acquainted with Viollet-le-Duc's "Mont Blanc" of the small lakes held in place upon that mountain by like ridges, which are described as undoubted old moraines.

The mouth of North Basin is shut across by a low hill, to be seen in the heliotype. Viewed from the northern summits, it seems to be the last deposited terminal moraine of a glacier which once occupied that basin; but on closer inspection its aspect changes, and it is to be regarded only as a possible, not a probable moraine. And, indeed, as is implied in the foregoing statements, the moraine-like form and location of the elevations which have been considered should be held, prior to thorough investigation, as indications that they may be, rather than proofs that they are, deposits from local glaciers.

Whether the depression on the northern side of the "Horseback" was, or was not, the track of veritable glaciers of a former period, it is now occupied at intervals by moving masses that approach as nearly to the character of glaciers as changed climatic conditions permit. The hollow is so broad, comparatively shallow, and smoothly concave in outline, that it cannot have been fashioned by running water, which on Ktaadn leaves its mark always in deep and narrow gorges. At about the middle of the concavity an open strip, ten or twelve rods wide, and completely cleared of trees, runs down the slope, for more than a mile from the bare upper mountain, through thick woods below. The growth, at the intermediate point where we struck the strip, is one of spruces twenty feet high, that rise like a wall on either side of the square-cut opening; while the strip itself is covered with growing bushes that averaged, last September, less than five feet high. Among the bushes lay prostrate, with their tops pointing down hill, small spruce trunks, bleached and dry, and evidently for some years dead. None of them were more than ten feet long. The dead trunks had been simply broken near the ground, and still lay attached to or near their bases. That the movement which cleared the strip is one that occurs only at intervals of some years, is proved by the considerable size the trunks had attained before they were broken down; and that at least one descent had taken place since that which felled them is shown by the fact that the eastern border of the strip, for a width of two rods, was free from bushes, but was covered with levelled spruces as large as those of the adjacent wood, and still retaining their branches and bark in nearly fresh condition. Here the thickness of the trunks was so great that they were not broken, but the roots were torn from the scanty soil on the upper side, leaving in the earth those that extended in the downhill direction. The mass that last descended was two rods wider on the east than any other which for many years had passed down the path. It must have levelled, for the time being, the bushes, whose elasticity saved them from breaking, and restored them to the upright position.

The inclination of the hollow, through its wooded portion, is moderate for Ktaadn. It is evident that snow, accumulated on the bare and steeper slopes above, under conditions that have recurred only after periods of some years, has swept down as an avalanche with an impetus that bore it far over the forest-obstructed smaller slope below.* In its progress it has successively prostrated, buried, and passed over the opposing small trees, in no case, at the intermediate part which we saw, carrying away the trunks or branches.

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* Under peculiar conditions, a trifling slope may serve, not only for the transmission, but for the origin of an avalanche. In Augusta a street, 100 feet wide, runs west from the river directly up the terraces before described to the general level

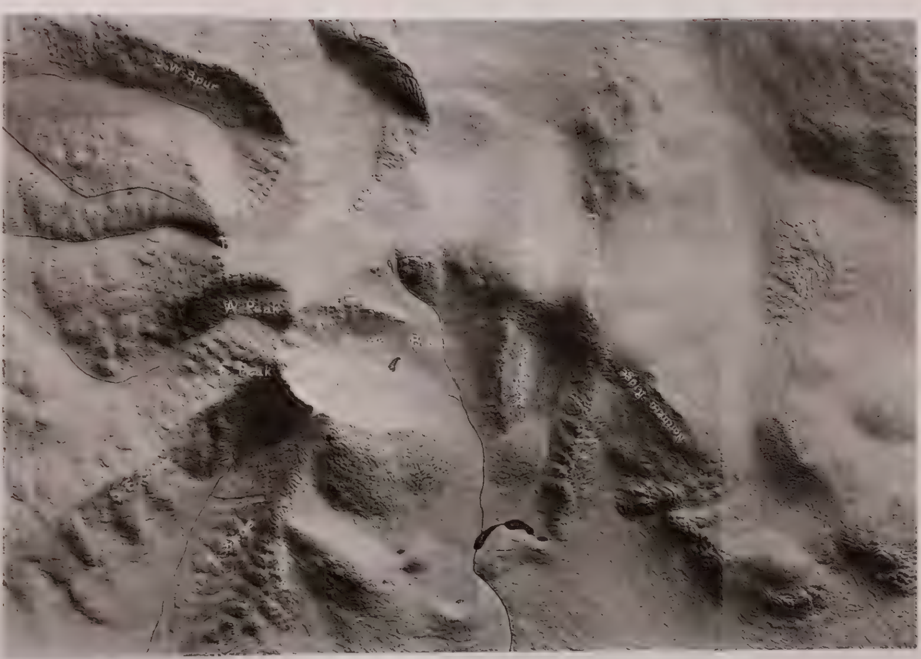
Certain huge blocks of granite that lie on the floor of the South Basin have been regarded by some as erratics, but in fact are parts of the adjacent cliffs, and owe their present location indirectly to the agency of ice. They are fragments of the eastern wall, which, falling upon inclined planes of compacted snow or ice accumulated in winter against the basin sides, have slid or rolled several rods beyond the great talus, 350 feet in height. Lying so far beyond the talus, which is the receptacle of most descending fragments, they have been mistaken for erratics, notwithstanding their agreement in composition with the nearest cliffs. In the same way alone can we account for the presence of great rock masses at stations so far out from the northern foot of Pamola that they cannot be supposed to have rolled thither over any other surface than an inclined plane of ice. Here, too, somewhat west from where the foot of the cleared strip must be, are four approximately parallel ridges made up of granite blocks of all sizes. They are of considerable length, and have between them hollows fifteen or twenty feet deep and some rods wide, but of unequal width. They appear too recent, — resembling parallel tali of fresh material, — and too near together, to correspond to my notion of old terminal moraines; and I was unable to explain their origin in any way satisfactory to myself.

A change that was produced in a part of the southern lobe of South Basin, during the early summer of last year, is instructive, as illustrating the origin of the Ktaadn slides. The gorge between the Chimney and the peak of Pamola — a typical instance of erosion — is a deep and narrow cut, forty feet wide at its head, diminishing to ten at the foot, and upon its floor to two or three feet at the outlet, where it is a polished, concave water-course worn in the solid rock. Its small drainage area, and evidence derived from the accumulations about its foot, show that even in times of flood it ordinarily carries a stream of but moderate size. In the summer of 1879 the débris that had been brought down in a series of years extended downward from the foot in the usual fan-shaped "cone

above. The hillside from the upper terrace to the top is 1,300 feet in length. The inclination of the street near the summit is 11°; midway, 7°; below, from 3° down to 0°. Early in the winter of 1878–79, the snow, after continued rain, assumed the slushy state, and, starting from the middle of the hill, where the inclination is only 7°, rushed suddenly down the street with a roar, and piled itself on the level ground at the foot. On the steeper upper half the snow lay unmoved. In the ninety years since the street was opened, this is the only case of the kind recorded.

of dejection," rendering passable the portion it overspread of the talus, which, except at like places, is almost inaccessible from its base, being there made up of huge blocks like "monolithic houses tumbled together by an earthquake." The cone was furrowed by no deep channel, such as would have been formed had a large and powerful stream passed over it. In September last the whole had been changed. Without pausing for details, it is enough to say that a gully had been cut to a depth of fifteen feet, down which, at a quarter of a mile's distance, was piled, twenty feet high, a heap of bowlders, varying from ten feet in diameter down to those of moderate size, all mingled with earth and gravel. Here the first rush of water which effected the change was checked, and its course deflected. Lower down, smaller blocks were distributed in the order of their size; then came cobbles, next pebbles, then gravel, till at the distance of more than half a mile, and near the Basin Pond, one stepped suddenly down from a square-ending sand terrace two and a half feet high. Such an exhibition of material assorted by water, within so small a space, is rarely to be seen. A water-spout, or "cloud-burst," upon the peaks had wrought the havoc. It must have been confined to a narrow area, for signs of disturbance were wholly wanting on the talus half a mile north; and in the bed of the torrent, less than a mile distant, which descends from the Saddle and was both years our daily route from camp at the Basin Pond to the summits, no change from the previous year had happened. The time of the occurrence was fixed by valid proof. Scrub birches were found in the course of the flood completely stripped of bark, but often retaining at the tips of their highest twigs shrivelled leaves, which showed by their thinness that the shrubs had been torn from place just as the leaves were fully expanded.

Heliotype taken from a model of Mt. Ktaadn, representing the upper three thousand feet of the mountain, and an area of about ten miles in length by seven in width. The vertical scale of the model is three times greater than the horizontal. Lack of shade renders some of the features indistinct.


S.W. Spur
W. Peak
Peak

No. 6. — *Report on the Recent Additions of Fossil Plants. By* LÉO LESQUEREUX.

IN the department of Paleophytholog the collections of the Museum have been this year greatly increased by the following contributions: —

1. The Smithsonian Institution has presented one hundred specimens of tertiary and cretaceous plants, obtained by the U. S. Geological Surveys of the Territories under the direction of Dr. F. V. Hayden. They are referable to species published in the Cretaceous and Tertiary Floras, Vols. VI. and VII. of the U. S. Reports.

2. More than six hundred specimens of cretaceous fossil plants have been obtained in the Dakota group of Kansas by Mr. Charles H. Sternberg. These specimens, in a remarkably good state of preservation, represent forty specific forms, of which about twenty are new, and six known only as yet by the descriptions of Professor Heer.

The new species are referable, like those published already from this formation, to all the essential divisions of the vegetable kingdom. The Cryptogamous have fragments of a *Jeanpaulia?* and of an *Equisetum*. The Conifers are represented by a large *Thuites;* the Cycadeæ, by three or four species of *Podozamites*. The Phænogamous *Apetaleæ* have a *Myrica*, an *Alnites*, a *Quercus*, two species of *Ficus*, and a *Laurophyllum;* the *Dialypetaleæ*, an *Aralia*, three distinct forms of *Araliopsis*, a *Cissus*, four species of *Liriodendron*, an *Anona*, a *Greviopsis*, a *Sapindus*, and a *Rhamnus*. Besides these new species there are in the collection specimens of *Populus litigiosa*, *Ficus primordialis*, *Diospyros primæva*, already described by Heer from the Dakota group, with *Proteoides lancifolius*, described by the same author from the European Cretaceous of Quedlinburg, and *Magnolia speciosa*, from that of Moletin. Some other very rare species, like *Populites elegans*, *Platanus primæva*, *Magnolia tenuifolia*, *Liriodendron giganteum*, *Aralia Towneri*, *Aralia saportanea*, divers species of *Protophyllum*, and especially *Aspidiophyllum trilobatum*, are represented also by numerous beautifully preserved specimens. Taken all together, this collection is therefore a valuable acquisition for the Museum.

It is not less valuable in regard to the data which it affords in confirmation or contradiction of some of the general conclusions derived from the examination of the materials formerly described from this peculiar cretaceous flora.

For example, the disconnection of the flora of the Dakota group from that of the older ones, those of the Jurassic times, does not appear now as positive as formerly, or as it was indicated in the Cretaceous Flora, Vol. VI. of the U. S. Reports. For besides the *Pterophyllum* described in that volume as somewhat doubtfully referable to the Cycadeæ, plants which essentially constitute the vegetation of the Jurassic, we have now four species of the genus *Podozamites* either identical with or closely related to species known from this formation.

Per contra, the disconnection of the Cretaceous flora from that of the lower Tertiary appears now still more evident, as the new species do not indicate any affinity to the plants of the Laramie group, which is positively Eocene by its types. As yet no vegetable remains distinctly referable to Palms have been found in the Dakota group.

The vegetation of the Cretaceous seems to be essentially composed of synthetic types, genera or groups of plants of analogous characters, which it is extremely difficult to define and separate into species. And nevertheless, when considered separately, the leaves, which are as yet the only organs obtained for analysis, show points of difference so marked that it is not well possible to consider them as representing mere varieties. To prove this assertion, it is sufficient to examine the so-called species described under the generic names of *Populites*, *Platanus*, *Araliopsis* (a new division which includes most of the leaves described as *Sassafras*), *Aralia*, *Protophyllum*, *Menispermites*, etc. One of these types, however, the more peculiar and distinctly cretaceous in its facies, *Liriodendron*, was until now represented by few diversified forms, and therefore considered as simple, and the supposition seemed confirmed by its passage, with *Platanus*, *Sassafras*, and *Fagus*, through all the geological ages from the Cretaceous to our time, with scarcely any modifications and few representatives. But now the collection of Mr. Sternberg eliminates this exception, as we find in it four new and very distinct forms of this group, besides a beautiful entirely preserved leaf of *Liriodendron giganteum*, which had been described from a mere lateral lobe, and which was therefore of uncertain attribution.

A short description of this genus, and of its species as exposed by the leaves, may show how uncertain, though binding, are the characters of the Cretaceous leaves.

GENUS *Liriodendron.* Leaves panduriform, oppositely bilobed ; lobes oblique or in right angle, obtuse or acuminate ; midrib thick ; lateral veins in right angle, opposite or irregularly alternate.

1. *L. giganteum.* Leaves large, twenty centimeters broad between the lower broad (six centimeters), oblong, obtuse or rounded lobes ; upper lobes shorter, slightly turned upwards, narrowed and rounded to an obtuse point, joining the lower in an obtuse sinus at a short distance (two centimeters) from the medial nerve.

This form is the one more distinctly related to *Liriodendron tulipifera*, the species living at our epoch. It cannot be considered identical with it, however, the difference in the characters of the leaves being too marked, but not more so than in the following forms, which I consider as new species.

2. *Liriodendron acuminatum*, sp. nov. Leaves small, about half as large as in the preceding species, cut in two pairs of narrow linear acuminate lobes, about one centimeter broad, all curved upwards.

3. *Liriodendron cruciforme*, sp. nov. Leaves large, upper lobes broad, square or equilateral, in right angle to the broad midrib ; lower lobes narrow, linear, acuminate, much longer and turned upwards. The shape of the leaves is like that of an anchor, except that the medial nerve or axis does not pass above the upper borders of the lobes.

4. *Liriodendron semi-alatum*, sp. nov. Leaves divided at the base in two opposite short rounded lobes (one on each side) curving up to near the medial nerve and then enlarging upwards into an obovate or spathulate entire lamina.

5. *Liriodendron pinnatifidum*, sp. nov. A single leaf with the general facies, and the venation of a *Liriodendron*, but subalternately trilobate on each side. The top of the leaf is broken.

Besides the above forms, there have been described already, from the Dakota group, *Liriodendron Meekii*, Heer, a species with comparatively small leaves, only three to five centimeters long, two to four centimeters broad, the lobes equal in length, short and rounded ; and *Liriodendron primævum*, Newb., from a leaf of which the upper half is destroyed, and whose characters are not sufficiently defined. By the size of the leaves, the species is intermediate between *L. Meekii*, Heer, and *L. intermedium*, Lsqx. ; form also known from a single lacerated leaf, which, narrow in the middle, has long obtuse lobes turned upwards, and a facies different from that of any of the other forms described. We have thus eight specific forms of leaves representing the clearly defined type or genus *Liriodendron*, all differing so greatly that it is not possible to consider them as mere varieties of one species only, and nevertheless of characters so closely allied that their specific identification seems to be hazardous. And this, as said above, is the case with most of the so-called species of the Dakota group.

The difficulty is increased by the fact that by gradual modification the leaves pass to evidently different generic types. The genus *Liriophyllum*, for example, represents leaves of *Liriodendron* nearly round in outline, but split at the top and to below the middle in two lobes joined in a narrow sinus upon the medial nerve, a peculiar division and facies which have no analogy in any species of plants of our epoch. This new genus is by its leaves intermediate between *Liriodendron* and *Populus*.

The local distribution of the leaves may be relied upon to give some directions for the separation of species. For of course if the analogous forms are found in separate and distant localities, the marked differences are more likely to be specific. On this subject the specimens collected by Mr. Sternberg afford good opportunity for examining the question. Omitting details, it suffices to mention what is known of the distribution of the leaves of *Liriodendron*.

L. Meekii is described from specimens found in Nebraska and Minnesota only. The specimen of *L. primævum* is labelled Blackbird Hills, Nebraska. This form is allied only to *L. semi-alatum* of Kansas. *L. intermedium* is also from Nebraska, represented in one specimen only, and has no affinity with any of the Kansas species. *L. giganteum* was first described from a fragment found near Fort Harker, Kansas, while the specimen of the Museum is from two and a half miles from Glascoe, in another county, where also were found *L. acuminatum* and *L. pinnatifidum*, whose leaves have little affinity of characters between them. *L. semi-alatum* was found at a different locality seven miles distant from Glascoe, and *L. cruciforme* at Elkhorn Creek, twelve miles northwest of Ellsworth.

From this kind of distribution it seems legitimate to conclude, not only for *Liriodendron*, but also for all the other groups of this flora whose leaves present the same degree of affinity or of difference, that, if the forms are derived from synthetic types, and if they are found somewhat modified in characters at distant localities, it is a proof that the modifications are already fixed, have become local characters, and that they may be considered as specific.

On another question, that of the derivation of the vegetable remains found in the strata of the Dakota group, and of their distribution, either in place, from trees grown there, or as transported by water from distant localities, a question examined already in the Cretaceous Flora, the collection of Mr. Sternberg affords the same degree of evidence as for the preceding.

It has been observed in the Flora, Vol. VI., *loc. cit.*, that the Cretaceous leaves and other remains of plants are found always spread over small areas, generally less than one or two acres in surface, and far distant from each other, so that in travelling over the prairies of Nebraska and Kansas, the collector may wander for twenty to forty miles or more without discovering a single fragment of fossil vegetable, and abruptly come to one rich deposit where leaves are found in abundance. Generally each of these deposits has remains of plants of a peculiar group, even sometimes of a single species. For example, *Aspidiophyllum* leaves are from one place only; *Aralia Saportanea*, from two widely distant. *Protophyllum* and *Sassafras*, or *Araliopsis cretaceus*, and its varieties, abound at Thompson's Creek, while species of *Salix* and *Podozamites* are from Elkhorn Creek and Glascoe; and so on. The localities where the specimens examined were found are twenty in number, and in each of them only two to a dozen species have been recognized. A grouping of this kind shows that the leaves were derived from trees grown in place where the leaves are now found, the trees apparently covering hillocks, or dry surfaces of land, disseminated in wide lagoons. As floated from a distant shore, the leaves should be more or less, but always, mixed. Their fine state of preservation, their position generally flat, confirm this supposition.

3. A second lot of specimens from the same formation has been procured for the Museum in Colorado, near Morison, by Rev. Arthur Lakes. The number of specimens is small, and the species which they represent are all, except one, already known from the Dakota group of Kansas. Among them are *Proteoides grevilliæformis*, *P. daphnogenoides*, *Magnolia alternans*, *M. Capellini*, described by Heer in the Phillites of Nebraska. *Sassafras cretaceus*, Newb., *Salix proteæfolia*, with *Liriophyllum populifolium*, *L. Beckwithi*, *Aralia Towneri*, *Sterculia lugubris*, and species of *Ficus*, most of them found in Kansas, and already figured for the eighth volume of the U. S. Reports. One of the species only, a peculiar small form of *Liriophyllum*, is new.

4. The last addition of this year to the phytopalæontological department of the Museum has been made by the acquisition of nine hundred specimens of coal plants from Mr. I. T. Mansfield of Cannelton, Pennsylvania. This locality has until now furnished to the coal flora an abundance of vegetable remains of species rarely found elsewhere. Of the genus *Cordaites*, for example, formerly known by separate leaves or mere fragments of leaves only, specimens have been found there with branches bearing leaves, and even flowers and fruit. A proportionately large number of specimens of this kind are in the Cannelton collection.

which represents fifty species, mostly in finely preserved materials. Among the species worth mentioning are *Odontopteris cornuta*, *Callipteridium inæquale*, *Alethopteris ambigua*, divers species of *Stemmatopteris* and *Caulopteris*, *Lepidostrobus spectabilis*, *Lepidophyllum Mansfieldi*, *Sporocystis* and *Lepidocystis* species, *Tæniophyllum decurrens*, *Rhabdocarpus Mansfieldi*, all peculiar to the locality, or not as yet found elsewhere, and splendid and numerous specimens of the rare spikes of *Macrostachia infundibuliformis*, *Neuropteris cordata ?* Brgt., or *Cyclopteris trichomanoides ?*, *N. heterophylla*, Brgt., *Pseudopecopteris Pluckneti*, and *P. anceps ;* many specimens of *Spiropteris*, circinnate branches of ferns (spirally coiled inward in the process of unfolding), of *Sigillaria monostigma*, of *Artisia* (decorticated stems of *Cordaites*), of *Cordaianthus* (their flowers), of *Cordaicarpus* (their fruits), etc. As the Museum had not any specimens of that peculiar locality, these plants constitute an important addition to the collection.

With the materials obtained this year the Museum has now in fossil plants : —

1. From the Devonian, a series of specimens presented by Professor J. W. Dawson and Mr. C. T. Hartt from the measures of Canada, and from England a number of very fine ones, presented by Sir Charles Lyell. Among these is a splendid fruiting pinna of *Archæopteris Hybernica.*

2. From the Carboniferous, a large number of the best specimens found in the nodules of Mazon Creek, the shales of Morris, and other localities of Illinois ; numerous and good specimens from the anthracite basins of Rhode Island and of Pennsylvania ; fine materials from divers localities of Ohio and Kentucky, presented by Mr. Anthony ; rare specimens from the subconglomerate measures of Ohio and Tennessee ; and the collection of Cannelton mentioned above.

3. From the Cretaceous of the West the Museum has now an amount of materials sufficiently representing the Dakota group. Fine and numerous specimens can be spared for exchange.

4. The Tertiary of this continent is insufficiently represented in the Museum by a number of specimens presented by the Smithsonian Institution, and by a few sent by Rev. Arthur Lakes from Golden, Colorado. There is, *per contra*, from Europe a splendid collection of Miocene plants purchased from Professor Heer, of Zurich, and a number of undetermined specimens from divers formations and localities, mixed with animal remains, in the collection of Bronn.

No. 7. — *The Great Dike at Hough's Neck, Quincy, Mass.* By John Eliot Wolff.

This dike is situated some two and a half miles northeast from Quincy Depot; rising, when first seen, as an irregular ridge, and continuing, with interruptions, for about a mile in an easterly direction.

Mr. Crosby has mentioned this locality in his "Contributions to the Geology of Eastern Massachusetts": * — "On Hough's Neck, in Quincy, the amygdaloid is a green, slaty rock; it is sometimes amygdaloidal, and sometimes porphyritic, and includes masses which resemble felsite. It occupies the axis of an anticlinal in the conglomerate; and also cuts the latter rock very freely, after the manner of an eruptive." (p. 176.) Again: — "On Hough's Neck, in Quincy, along the north side of Rock Island Cove, there are prominent ledges of conglomerate flanking a large mass of amygdaloid, and the latter rock crops through the former in isolated bands, due to extravasation or faulting. The conglomerate strikes about east-west, and shows nearly vertical dips to the north and south, dipping away from the amygdaloid. It holds unmistakable pebbles of Shawmut breccia. This is clearly a faulted anticlinal fold. Toward the north, over the area marked as slate, the rocks are all concealed by drift; but on the south the conglomerate shows very plain indications of a passage to slate." (p. 209.) The amygdaloid, constituting a member of Crosby's Shawmut group, is regarded by him as older than the overlying Primordial conglomerate, and as a sedimentary rock in general, though sometimes presenting evidence of intrusion.

The country rock of the dike is a coarse conglomerate, with occasional interbedded layers of red sandstone and slate. At the eastern end it is bordered on both sides by the conglomerate. After running for a quarter of a mile as a ridge, the dike suddenly loses its ridge character, and occasional exposures only are found in the field to the east, among the outcropping conglomerate ledges. It can be traced thus for a quarter of a mile; then for some hundred feet no outcrop of dike is found until a small creek is reached. Crossing this, however, we again find a dike continuing as a ridge in the same direction for some hundred yards, when it disappears under the drift of a headland. This exposure, however, is not in the line of strike of the main, or westerly part of the dike, but lies some hundred feet to the north. Whether this change is due to a horizontal throw, or to a fresh outbreak of dike along a parallel line, does not appear.

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* Occas. Papers, Bost. Soc. Nat. Hist., III., 1880.

At the western end, on the southern side, the junction with the conglomerate and red sandstone is very irregular, — large and small tongues of the dike penetrate into the conglomerate, this rock having a strike N. 60°–80° W., and a dip 70° south. The junction between the two rocks is sharp and well marked : the dike seems often amygdaloidal near the junction. Sections of the contact of the two rocks show that the dike is composed of a mass of very small feldspars, having a beautiful fluidal arrangement, while they are often bent when in contact with the line of the conglomerate. On the northern side, a fine vertical exposure of the junction is obtained, which is seen to stand almost vertical ; the dike cutting the slate and conglomerate a little irregularly, but standing nearly parallel to the stratification. The conglomerate here is nearly vertical, but may be said to dip to the north very steeply ; if, however, we pass east along the strike, a few hundred yards, to the exposures in the field, we find that all the conglomerate, both north and south of the line of the dike, dips steeply in one direction, i. e. south. I cannot, therefore, agree with Mr. Crosby, that "this is clearly a faulted anticlinal fold." It may equally well be an intrusion of the dike into the vertically standing strata, causing irregularities of the dip. More detailed study is required. In the western ridge the dike has a width of about three hundred feet from contact to contact.

The rock is generally of a greenish color, approaching a greenish red in the fresher portions ; it is irregularly jointed. In texture there is great variation between coarse, fine, porphyritic, and amygdaloidal. Masses of quartz, and yellowish-green epidotic material frequently occur. These greenish masses are often very irregular, occasionally vertically banded, and resembling fragments of a stratified rock, and often lined on the exterior with a band of reddish substance. Microscopic sections of some of them give a mixture of quartz, calcite, epidote, and a whitish opaque substance (kaolin ?), and show that they are in part areas in the rock of decomposition, or segregation.

Although at first sight this dike appears to be a homogeneous mass of rock, yet it is in reality composed of rocks belonging (in all probability) to at least three separate eruptions, forming, instead of one, numerous dikes. To this fact is largely due the noticeable variations in the area of rock. First in order comes the amygdaloid, forming the principal mass of the rock, and eruptive through the conglomerate. In the second place, a close study of the great area of this rock shows that it is cut by a large number of narrow diabase dikes, generally but a few feet in width (e. g. three feet), which do not have a marked amygdaloidal structure. In many cases they run almost parallel with the trend of the amygdaloid; in other cases they run obliquely, while others again may cut almost transversely across it, in parallelism with a third dike to be mentioned. These dikes show generally well-marked contacts with the amygdaloid: they are fine-grained at the junction, but coarse-grained in the centre; in some cases they have melted the amygdaloid at the contact, so that it is difficult to find the actual line. Some of them are easily distinguished from the amygdaloid, under the microscope, by the large amount of augite which they contain, but in others this mineral cannot be found as such, for all trace of it (if originally present) has been lost in the alteration products. Lastly, about the middle of the large western exposure of the amygdaloid there is found a large dike (at least seventy feet wide) running transversely across it, in a direction N. 5°–10° W. On the south side it is seen breaking through the conglomerate and sandstone, and can be traced from that locality across the amygdaloid. No exposure was found giving the actual contact of this rock with any of the others, although it can be seen at a distance of a foot or two from them. Judging from its direction, which cuts directly across the trend of a great number of the small dikes, it would seem to be the latest rock of all. Some of the small dikes to the east of it are, however, nearly parallel with it. While, therefore, there seem to be at least two periods of eruption subsequent to that of the amygdaloid, yet some of these small dikes may cut the others, thus complicating the phenomena still further. I have not been able to find evidence of this beyond the difference of direction; and to settle the question by the discovery of the actual contacts will be difficult, on account of the lithological similarity of all the eruptive rocks, and the thick covering of lichens, which conceals everything, and makes any work there laborious.

The amygdaloid sometimes loses its amygdaloidal character, so as to resemble greatly the later dikes; but in such cases the passage is gradual.

The microscopic descriptions which follow show that all these rocks are altered basalts, and, together with the field relations, prove that they are all truly eruptive rocks, breaking through the conglomerate, while the later eruptive rocks cut the earlier ones.

[1.] *From Western End of Dike, North Side, near the Road, — one of the small Dikes in the Amygdaloid.*

Lens. A greenish-gray, felty-looking rock, containing minute grains of pyrite, and small feldspar crystals. Traversed by veinlets of epidote. — *Section.* White opaque feldspar crystals, and masses of opacite, magnetite, and pyrite, in a green chloritic groundmass. The feldspars have generally the long ledge form of the basaltic triclinic feldspars, but occasionally the form of Carlsbad twins of sanidin. They are entirely altered to a fibrous and scaly aggregate, polarizing with yellow and blue colors, — often with the brilliancy of talc. Colorless needles with cross fracture (apatite) occur occasionally in the feldspars, and also aggregate quartz. Between the feldspars lies a mass of green fibrous products, — chlorite, viridite, etc., considerable epidote, magnetite, quartz, etc., — rarely hematite and biotite. The magnetite often has the form of a grating, reminding us of decomposed olivine. The feldspars occasionally have a fluidal arrangement.

[2.] *Contact of Amygdaloid and Conglomerate at Southeast Corner.*

Section. A mass of small feldspar crystals, having a well-marked fluidal arrangement, and surrounding decomposed crystals of olivine and masses of magnetite and opacite. The olivine crystals have the characteristic lozenge shape, blackened border, and irregular fissuring, while the small parallel feldspars of the groundmass separate and flow around the crystals. Some are altered within the black border to a light green serpentine with fibrous polarization ; in others, while the centre shows the brilliant polarization and the pitted surface of olivine (though the greenish color is evidence of some alteration), the exterior zone of the crystal has been altered to a bluish-gray substance, which in polarized light is seen to contain fibres with brilliant polarization, and may perhaps represent a stage in the alteration to talc. Some of the olivines are wholly or partially altered to ferrite and talc, the latter polarizing very brilliantly. Some of the magnetite and opacite in the section is derived apparently from the complete alteration of grains of olivine. The feldspars have generally the long ledge character of the basaltic feldspars, though some have the form and optical properties of Carlsbad twins. Occasionally there is found a crystal sufficiently fresh to show the multiple twinning, but generally they are filled with greenish or transparent scales, while along the centre of the ledge crystal there runs a line of green chloritic material, containing generally less opacite than the similar substances lying outside the crystal, but often continuous with them. Some of the crystals are more than half filled in the centre by a rectangular mass of this chlorite, often extending through to connect with that outside. The space between the feldspars is occupied by chloritic materials, opacite, etc., together with some quartz. Epidote and quartz occur in the groundmass as alteration products, and transparent needles, frequently broken across, which are probably in part apatite. Along the line of the conglomerate some of the feldspars are bent.

[3.] *West End of Amygdaloid very near* [1].

Lens. A gray-colored groundmass, containing white and greenish feldspar crystals, spots and crystals of epidote, occasional quartz and epidote amygdules, and reddish areas of decomposition. — *Section.* Composed principally of feldspars, with considerable epidote, chlorite, opacite, etc. The feldspars are mainly plagioclase, but there are occasional Carlsbad twins of sanidin. Some of the large porphyritic feldspars are broken and fragmentary; an effect, apparently, of the flowing base, for the small feldspars diverge, and flow around the large crystals. In some cases they are seen to have been pushed into the large crystals a certain distance on opposite ends along the central line, while a line of base passed through the crystal connecting the two tongues. This base, however, is now altered to calcite, chlorite, epidote, etc. Occasionally two feldspars interpenetrate each other. The products of their decomposition are the same greenish or colorless scales (which often have a brilliant polarization), epidote, chlorite, calcite, quartz, and colorless needles. The smaller feldspars seem less decomposed than the larger ones. Between the feldspars lie masses of chlorite, epidote, opacite, calcite, magnetite, etc.; often in the form of wedges between the diverging feldspars. One grain of altered olivine is seen in the section, identified by the shape and the previously described motion of the groundmass and base around it. The exterior consists of reddish ferrite, penetrating along the fissures; the interior of quartz.

[4.] *West End of the Amygdaloid near* [1] *and* [3], *but nearer in the Centre of the Mass.*

Lens. Similar to [3]. — *Section.* The large feldspars are broken by the base, as described above. Plagioclase and sanidin occur. True amygdules occur here, recognized as such by the regular shape, and by the fact that the small feldspars of the groundmass flow around the cavity and are distinctly separated from it. They are filled with epidote, chlorite, calcite, quartz, and a fibrous chalcedonic (?) material: the epidote is generally on the outside, the chlorite inside. Considerable epidote is scattered through the section, generally outside of the feldspars, and also talc, calcite, and quartz. These decomposition products often occur in the groundmass in rounded areas, but are not true amygdaloids. Patches of reddish opaque ferrite also occur in a similar manner, constituting the red spots seen macroscopically.

[5.] *Western Ridge of the Dike on the West Side of a Road which crosses it, — taken towards the Centre of the Mass.*

Lens. A greenish groundmass containing porphyritic feldspars, reddish and greenish areas of alteration, and rounded masses of quartz. The groundmass has intruded into some of the large feldspars. — *Section.* Crystals of feldspar and areas of decomposition or infiltration surrounded by a greenish chloritic mass. The large feldspars are occasionally Carlsbad twins; the small ones of the groundmass principally plagioclase, although some are twinned sanidin crystals. The (original) base, carrying small feldspars, has bent some of the large feldspars, and pushed into them. Others contain in the centre square zonal inclusions of the greenish mass, while the outer zone of the crystal is free from it. These phenomena are similar to those so frequently observed in the unaltered basalts with a glassy base. Many of the larger feldspar crystals are partly filled with epidote grains, chloritic material, and light-green needles, which have a yellowish-white polarization. Rounded areas, composed of greenish chloritic fibres, with sometimes a deep violet blue color between crossed nicols, occur in the groundmass, mingled occasionally with talc, and bordered by epidote. Some of these areas, enclosing the remains of the small feldspars, arise from the decomposition of the groundmass; others are either true amygdules, as described above, or some might be pseudomorphs after some mineral, — for instance, olivine. Between the feldspars lies the green mixture of chlorite, viridite, and greenish needles similar to those described in the feldspars, beside some epidote, calcite, and quartz.

[6.] *Western Ridge of the Amygdaloid, about fifty feet east of a Road crossing it, — the Specimen taken from a long Dike crossing the Amygdaloid obliquely to its Main Trend.*

Lens. A grayish-green groundmass, holding crystals of greenish feldspar and grains of pyrite. The groundmass has pushed into some of the long crystals. Powder feebly magnetic. — *Section.* Much decomposed. The feldspars retain their outline, but are filled with chloritic material, — kaolin, epidote, and calcite. Magnetite is very plentiful in crystalline and irregular forms, having often a whitish, decomposed surface (leucoxene), which, in connection with the reticular or branching shape of the masses, shows the presence of menaccanite. Pyrite occurs in occasional grains and square crystals, generally close to or mingled with the magnetite or decomposed menaccanite, and is therefore probably an alteration product. The remaining portion of the rock is a confused mixture of chlorite, epidote, quartz, viridite, hornblende, calcite, and colorless needles, in part probably apatite, — all products of alteration. This rock is the most coarsely crystalline and the most decomposed of any examined.

[7.] *From the Exposure of the Dike in the Field midway between the extreme Eastern and Western Ridges.*

Lens. Similar to the preceding hand-specimens, but rather reddish in color, and somewhat more amygdaloidal. — *Section.* A much fresher rock than those already described. The few porphyritic feldspars are generally plagioclase, and exhibit the same proof of an early crystallization mentioned above (i. e. the feldspars of the groundmass flow around them, etc.). The feldspars of the groundmass are principally plagioclase, but some Carlsbad twins and unstriated crystals can be found. All these feldspars are comparatively fresh, and the formation of the greenish scales and other products of decomposition has not progressed far. The frequent inclusions of the original base, however, are entirely altered to chloritic products and magnetite. The feldspars contain occasional large rounded or irregular fluid inclusions, with bubbles, and immense numbers of extremely small similar inclusions (requiring the use of powers of from 700 to 900) characterized also by occasional moving bubbles. Grains and crystals of epidote occur in the feldspars, and occasionally quartz. Chloritic products and magnetite represent the original base. Epidote occurs in the groundmass in patches; calcite is rare. True amygdules occur, filled with chlorite, quartz, and epidote.

[8.] *From the Ridge constituting the extreme easterly Exposure of the Dike, and not in Line with the Western Half, though trending parallel with it.*

Lens. A reddish groundmass, containing feldspar crystals, amygdules of greenish chlorite, and red spots resulting from the decomposition of the rock. — *Section.* The least decomposed rock of any examined. It has a groundmass composed of small ledge-shaped feldspars, magnetite, chlorite, epidote, etc., enclosing porphyritically a few large feldspars. The majority of the crystals are plagioclase, but there is a considerable number of Carlsbad twins. The small feldspars of the groundmass show the flowing of the base around the large crystals, as described previously. The larger feldspars contain very characteristic inclusions of a base in irregular, reticulated, or cylindrical forms. They often fill a large part of the crystal; may be zonally arranged; and are absolutely identical in shape and other characteristics with the inclusions of glass or base in the unaltered basalts. These inclusions are now altered to magnetite and greenish chloritic or viriditic products. Besides these dark inclusions of base, the feldspars are filled with almost colorless microliths and scales, — the products of the incipient decomposition of the feldspathic substance, — and very minute fluid inclusions, rounded, cylindrical, or branching. Some epidote and calcite occur in the feldspars. True amygdules are found, filled with calcite, epidote, and chlorite. Irregular masses of epidote occur as areas of alteration in the groundmass, — the magnetite often in large masses, enclosing the small feldspar crystals of the groundmass, and mixed with considerable ferrite. One decomposed crystal may perhaps be referred to olivine.

[Q. 8′.] *The Large Dike running nearly at Right Angles across the Trend of the Amygdaloid.*

Lens. A coarse-grained, dark green rock, containing crystals of feldspar, pyrite, magnetite, and hornblende, in a dark green groundmass. — *Section.* Contains (comparatively speaking) large-sized feldspar crystals; fibrous, greenish, dichroic hornblende; crystals of magnetite and pyrite; decomposed crystals of olivine; epidote; and viridite, quartz, apatite, etc. The feldspars are to a great extent kaolinized. The hornblende occurs in irregular masses, shows strong dichroism and brilliant polarization, and contains a great deal of epidote in rounded grains. Some of the feldspar crystals lie imbedded in the hornblende, or cross it, just as they do in the case of the augite of the less decomposed diabases, so that this and the whole character of the hornblende indicate that it is (in part at least) a product of the decomposition of the original augite. The olivine occurs generally in shattered crystals, with the usual blackened border. The interior is altered to greenish serpentinous products; but little spots still show the polarization and other characteristics of the unaltered olivine. The magnetite is found in extremely irregular forms, while the pyrite grains often contain magnetite, and therefore arise probably from its decomposition.

[Q. 1'.] *One of the Narrow Dikes running parallel with the Trend of the Amygdaloid.*

Lens. A compact greenish rock containing crystals of feldspar. — *Section.* Contains feldspar crystals, augite, magnetite, pyrite, and decomposition products. The feldspars are kaolinized, or else decomposed to white fibres, and contain considerable epidote, viridite, etc. The augite occurs in irregular masses; it is reddish and has well-marked cleavage; the decomposition to viridite, hornblende, and epidote is seen to be well advanced, these substances forming along the cleavage lines. The magnetite often shows the white decomposition characteristic of menaccanite. The pyrite is probably derived from the magnetite. No traces of olivine were seen.

[9.] *Section of Two Pieces of the Greenish vein-like or irregular Masses found in the Rock.*

One of the fragments is composed of epidote, calcite, quartz, and an opaque gray substance, perhaps kaolin, — mixed with the remains of feldspar crystals. The other fragment, from one of the banded veins, is composed of the same substances arranged in bands. Both are probably areas of decomposition in the rock.

Summary.

From the details given we obtain the following generalized description of the amygdaloid proper. In the hand specimens the groundmass varies in color from green, through gray, to red, — the last color characteristic of the rock that is least decomposed. It sometimes encloses large green or white feldspar crystals, often indented by the groundmass, or the feldspar crystals may be comparatively minute; grains and crystals of epidote are occasionally seen. The rock generally contains greenish spots of epidote and of chloritic material, in part true amygdules, and spots of reddish decomposition. There are also amygdules of calcite and quartz.

The specimens from which the eight sections were made differ chiefly in the degree of decomposition, the presence or absence of olivine, and the coarse or fine texture. The specimens from the eastern end are much less decomposed than those from the western end.

As seen under the microscope, the rock is composed of large and small feldspar crystals, magnetite, epidote, calcite, and a mass of chlorite, viridite, and opacite. The large porphyritic feldspars are twinned plagioclase, and occasionally Carlsbad twins of sanidin. The minute feldspars of the groundmass flow around them, encroach upon, and sometimes break them. Rarely, the groundmass, holding small feldspars, has pushed into a crystal, a little distance on either side, and a tongue of the (original) base, alone, without the small feldspars, passes through the crystal and connects the two intrusions, — this connecting tongue now altered, however, to calcite, chlorite, and epidote. The small feldspars, when sufficiently fresh, show the triclinic twinning; but some Carlsbad twins of sanidin and unstriated crystals occur, the former of which cannot be referred to the plagioclase that, owing to the alteration, does not show its multiple twinning.

The degree of decomposition that the feldspars have undergone varies in the different sections: in the freshest rock they contain immense quantities of minute fluid inclusions, characterized by moving bubbles, and occasional larger ones, rounded or irregular in shape, together with inclusions of the base. The latter are cylindrical, or irregularly reticulated in form, often zonally arranged in the interior or exterior parts of the crystal; they are absolutely identical in shape, and in their relations to the enclosing crystal, with the inclusions of glass or base of the fresh basalts; they are now altered to magnetite, viridite, and other products. In the smaller feldspars these intrusions generally run through the centre of the crystal, parallel with the twinning-plane. Even in the freshest specimens, the substance of the feldspars is filled with minute microliths, and scales either colorless or of a light greenish color, with occasionally some epidote, calcite, or quartz, — generally products of the decomposition of the feldspathic substance proper. In the more decomposed specimens these products multiply, so that the crystals become a mass of these viriditic scales and fibres (often polarizing with the brilliancy of talc, or in red and yellow colors), or even of opaque kaolin, while calcite, epidote, quartz, and colorless needles with cross fracture, in part apatite, appear to a greater or less extent. The epidote occurs generally in the large feldspars in grains: some of it may originate from the alteration of included minerals; but of this there is no proof. Occasionally two feldspars interpenetrate each other.

The only other original mineral, unless it be part of the magnetite and apatite, is olivine. This was found in well-marked, large, and undecomposed crystals only near the contact of the amygdaloid with the conglomerate (described with section [2]); though what seemed to be the remains of olivine crystals were found in one or two other sections. Their relations to the groundmass prove an anterior origin: some of the magnetite and opacite in the sections have probably been derived from the alteration of small fragments of olivine.

Between the large and small feldspar crystals lies a mass of greenish alteration products, — chlorite (often dichroic), viridite, magnetite, opacite, considerable epidote, quartz, and calcite. When some of the large feldspar crystals diverge, the triangular space between them is filled with very small feldspar crystals, lying in this greenish mass; showing, as has been often remarked, that it is merely an original, glassy base, much altered, for we find this same relation in the unaltered basalts. Calcite, quartz, epidote, hornblende, biotite, apatite, etc., in the decomposed base, seem to belong to the more advanced state of decomposition.

Magnetite is always present. A large part of the magnetite arises from the decomposition of the base, and it is generally difficult to say what part of it is original.

While in some sections true amygdules are wanting, yet they generally occur, characterized by their sharp boundary, and the arrangement of the feldspars of the groundmass parallel to their outline. They are filled by epidote, chlorite, viridite, calcite, or quartz; the epidote generally on the outside, when other minerals occur with it. Besides these true amygdules, areas of decomposition occur in the groundmass, consisting either of opaque ferritic material, constituting the macroscopical red spots, or of epidote, chlorite, viridite, etc., enclosing the small feldspars.

Assuming that all the specimens described belong to the same rock-mass, this rock, according to the classification used, would be referred to both the Diabase and Melaphyr sections of the Basalts* (according to the specimen examined), or again might be called a Diabase and Olivine-diabase.† It is found by study to be a rock which, in the original state, was composed of the feldspars, olivine, magnetite, a base (glassy, microlithic, etc.), and probably some augite (though this cannot be identified now), all in varying proportions, and that these original constituents have been largely replaced by secondary products. It is therefore an altered basalt, as has been previously shown by others for similar rocks of this region.‡

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* M. E. Wadsworth "On the Classification of Rocks," Bulletin Mus. Comp. Zoöl., Vol. V. No. 13.

† Rosenbusch, Mikros. Phys. der Mass. Gest., etc.

‡ M. E. Wadsworth, Proc. Bost. Soc. Nat. Hist., Vol. XIX. p. 217 *et seq.*, 1877. E. R. Benton, Ibid., Vol. XX. p. 416 *et seq.*, 1880.

The examination of the sections made from some of the narrow dikes which cut the amygdaloid seems to show, in general, a similarity to either [Q. 1′] or [6] — one series containing undecomposed augite, the other none that can be identified. The great cross dike is described under [Q. 8′]. All of these later eruptive rocks seem in a more advanced stage of decomposition than the amygdaloid.

July, 1882.

No. 8. — *On some Specimens of Permian Fossil Plants from Colorado.* By Leo Lesquereux.

Last February, Rev. Arthur Lakes, of Golden, wrote me that he had found in South Park, near Fairplay, Colorado, a bed of shale with beautiful insect remains mixed with a profusion of vegetable fragments resembling the scales and seeds of Conifers, and with them some well-defined forms, among others a small stem of *Lepidodendron*, showing distinctly the scars and various small branches of Conifers, or Zamiæ, or Lycopodiaceæ. "Those remains," he said, "are in the Red-beds, on an horizon appearing to us when examining the locality as Lower Triassic, or Permian, or Carboniferous. A thin seam of coal was also discovered, adjacent to the beds, and one tiny shell."

Some time later Mr. Lakes sent me a box of specimens from the locality mentioned above, asking me to determine them if possible, to report to him what evidence on the age of the formation could be derived from these vegetable remains, and to send the specimens to the Museum of Comparative Zoölogy at Cambridge.

Though the specimens are very small, covered with mixed minute fragments of leaves, scales, flowers, and seeds of Conifers, leaflets of Ferns, etc., I was able to recognize, in all those which could be determined, the characters of a Permian vegetation, and I reported to Mr. Lakes accordingly.

Being then about to publish the list of the determined species, with some remarks upon them, Prof. Samuel Scudder, to whom the insects had been sent, advised me that, from the characters of the animal remains, his conclusions on the age of the formation did not fully agree with those derived from the plants. As he was going to examine the locality himself, he wrote me that he might perhaps find some more valuable specimens, and that he would communicate them to me when returned home.

These specimens, kindly communicated by Prof. Scudder, were received two weeks ago. Though the vegetable remains preserved upon them are quite as broken, mixed, and indistinct as those of Mr. Lakes, I found a few of them whose determination added some new evidence to that which had been procured already.

The species which I consider as positively determined from all the specimens are the following : —

1. *Collection of the Museum of Comparative Zoölogy.*

CALAMARIÆ. — *Sphenophyllum Schlotheimii* Br., an entire perfectly preserved whorl. No. 1 of the collection.

FERNS. — *Odontopteris obtusiloba* Naum. Nos. 2 and 4.

Neuropteris Loschii Br., or *Cyclopteris cordata* Goepp. No. 6.

Fragment of an *Alethopteris* like *A. lingulata* Goepp. No. 7^a.

Five specimens of fragments of small leaflets of Ferns, not determinable. No. 18.

LYCOPODIACEÆ. — Leaves of *Lepidodendron*. No. 9. The stem of *Lepidodendron* recorded by Mr. Lakes, and rightly described by him in his letter, was not found in the collection.

CONIFERS. — Seeds of *Ullmannia selaginoides* Gein., Leitpfl. No. 8.

Scales or involucres of *Walchia* ! *linearifolia* ? Goepp. No. 10.

Young leaves of *Ullmannia Bronnii* Goepp. No. 11.

Leaves (detached) of *U. frumentaria* Goepp. Very abundant, and mixed with those of *U. Bronnii*. No. 12.

Leaves of *U. selaginoides* Gein. No. 13.

Branches bearing leaves of *Walchia piniformis* St. No. 14. Abundant and variable.

Fragments, mostly ground nearly to powder, of leaves, flowers, and seeds of *Ullmannia Walchia*, etc. Nos. 15 and 16.

Branch of *Ullmannia Bronnii* Goepp. No. 17.

2. *Collection of Prof. Scudder.*

CALAMARIÆ. — *Sphenophyllum emarginatum* Br. No. 9. Good specimen.

Fragment of rachis with a few leaves of *Sphenophyllum* species, Gein., as figured in Nachtr. zur Dyas, I., Pl. I. fig. 22.

FERNS. — *Schizopteris* species. Same as figured in Gein., Ibid., Pl. I. figs. 18, 18^b. No. 6.

Sphenopteris Geinitzii Goepp. No. 7. In many specimens.

Hymenophyllites Leucharti Gein. No. 8.

Cyclopteris rarinervia Goepp. No. 10.

Sphenopteris coriacea ? White & Font. No. 11.

Goniopteris Newberriana ? White & Font. No. 12.

Pecopteris arborescens Brgt., in fruit. No. 13.

Cyatheites Beyrichi Weiss. No. 14.

Callipteris conferta ! var. *obliqua* ? Weiss. No. 15.

Sphenopteris dentata ? White & Font. Nos. 15^a and 16.

Small fragments of Ferns indeterminable. Nos. 17, 18.

LYCOPODIACEÆ. — *Lepidophyllum* species. Sporange and blade. No. 5.

CONIFERS. — Leaves of *Walchia longifolia* Goepp. No. 20.

Leaves of *Abietites* Goepp. Fragments in many specimens. No. 21.

Leaves of *Ullmannia frumentaria* Goepp., and *U. Bronnii*, No. 1, abound.

Branches and leaves of *Walchia piniformis*, No. 3, in plenty of specimens.

CORDAITEÆ. — *Cordaites borassifolius* Ung. Very fine specimen. No. 4.

Fragments of leaves of *Cordaites* species. No 22.

Cardiocarpus orbicularis Goepp. No. 24.

Cardiocarpus species nov., allied to *C. gibberosus* Gein. No. 25.

Carpolithes species, one referable to *C. humidus* Heer, the other, very small but in plenty of specimens, to *C. Geinitzi* Heer, Perm. Pfl. of Funkirchen, Pl. XXII. figs. 5, 6, 7, 8, and 13. These are all mixed with ground fragments of scales, leaves, etc. of *Walchia* and *Ullmannia*. No. 26. Same as No. 16 of the collection of the Museum of Comparative Zoölogy.

On the above species of vegetable remains I add a few remarks in regard to their evidence for the determination of the age of the formation where they have been found.

The genus *Sphenophyllum* ranges from the Silurian to the base of the Permian, as far as known, at least, by the present state of our knowledge in vegetable palæontology. Three species of the genus are recorded by German authors, as from the Permian: *Sphenophyllum Schlotheimii*, *S. emarginatum*, and *S. longifolium*. But all are from the lower strata of the Old Red Sandstone, whose flora is so intimately connected by its characters with that of the Upper Carboniferous that the exact limitation between the formations has not been fixed. It is the same with the Permo-Carboniferous strata of Virginia, wherefrom a number of species of *Sphenophyllum* are described by White and Fontaine. Here we are not yet in the true Permian. A very small and obscure fragment of a *Sphenophyllum* species is described by Geinitz, Nachtr. zur Dyas, I., p. 10, Pl. I. figs. 22, 23. It is as yet the only trace of the genus in the Middle Permian. The specific characters are not discernible, and the author remarks that he has published it only because it is as yet the only species of *Sphenophyllum* found in the Permian of Germany. The presence of two species of this genus in the specimens of Fairplay would be already sufficient authority for referring the formation to the paleozoic time.

In the Ferns, the specimens represent *Neuropteris Loschii*, a species found already in the whole thickness of the Carboniferous, and also in the Permian of Europe. *Pecopteris arborescens*, Upper Carboniferous and Lower Permian. *Callipteris conferta*, one of the more abundant species of the Permian in Europe, and found until now on this continent only in the Permo-Carboniferous beds of Virginia. *Odontopteris obtusiloba*, *Cyclopteris rarinervis*, *Odontopteris cordata* which is scarcely distinguishable from *Neuropteris Loschii*, *Cyatheites Schlotheimii* var. *latifolia*, *Sphenopteris Geinitzi*, *Hymenophyllites Leuckarti*, as well as a *Schizopteris*, are all Permian species only. The other named species of Ferns are uncertain on account of the insufficiency of specimens, but they are referable to types of the Permian or Permo-Carboniferous.

In the Conifers, the most abundantly represented in the specimens of Fairplay are the two more distinctly characteristic of the Permian, *Ullmannia frumentaria* and *Walchia piniformis*. There are besides numerous leaves and branches of *Ulmannia Bronnii*, and leaves of *U. selaginoides*, of *Walchia longifolia*, and of *Abietites*, species all representatives of the same formation only.

In the Lycopodiaceæ, Mr. Lakes has found a branch of *Lepidodendron* which I have not seen among the specimens, but two of them have fragments of leaves of this genus, and a *Lepidophyllum* with blade and sporange. It is well known that the Lycopodiaceæ disappear at the base of the Trias, or rather in the Upper Permian. The same can be said of the *Cordaites*, of which *C. borassifolius* is represented upon the largest fragment of shale I have seen from Fairplay.

The age of a flora is indicated, not only by the presence of certain types, but by the absence of others. And in this, the group of vegetable remains in Fairplay is remarkably free of any fragments of plants characterizing the Triassic period. There is no trace of Equisetaceæ or of Cycadeæ. The fragments doubtfully referred to Cycas by Mr. Lakes in his letter are all leaves of *Ullmannia frumentaria* and *U. longifolia*. The Ferns are of a totally different character also. Prof. William Fontaine has prepared a memoir, descriptions, and figures of a large number of species of plants obtained from the so-called Triassic measures of Virginia, which he considers as the equivalent of the Rhetic of Europe. On these plants, Prof. Fontaine writes me that none of them could be referred to the Permian, or to any of the species which I have recorded from the specimens of Fairplay.

Possibly these Permian fossil remains will help to determine the geological distribution of the strata of South Park. In Dr. F. V. Hayden's Annual Report of 1873, Dr. A. C. Peale gives a section of the valley from Platte River to Trout Creek, on a distance of six miles. The section passes about five miles north of Fairplay. Its lower part, or beds No. 18 to 50, represent an open series of 1,250 feet of strata, all hypothetically referred by Dr. Peale to the Carboniferous or Permian, for no fossils of any kind were found to prove it. Above this there is a covered space (beds No. 51 and 52) of 1,300 to 1,500 feet, which is referred to the Red-beds or Triassic. The whole is covered by a thickness of Jurassic strata, overlaid by about 2,000 feet of Cretaceous. From this it appears very probable that the remains of plants found by Rev. Mr. Lakes first, and after him by Prof. Scudder, represent part of the first series of beds No. 18 to 50, all exposed and as yet hypothetically referred by Dr. Peale to the Carboniferous and the Permian. The exact location of the plant-bearing beds in the section of Dr. Peale may probably be easily determined.

OCTOBER, 1882.

No. 9. — *On the Relations of the Triassic Traps and Sandstones of the Eastern United States.* By WILLIAM MORRIS DAVIS.

1. INTRODUCTORY.
2. LITERATURE.
3. OBSERVATIONS. Nomenclature. — A, Turner's Falls. — B, Mount Tom. — C, West Springfield, Mass. — D, Beckley Station. — E, Meriden. — F, Wallingford. — G, New Haven, Conn. — H, Fort Lee and Englewood. — J, Weehawken. — K, Jersey City. — L, Paterson and Little Falls. — M, Feltville. — N, Martin's Dock. — O. Point Pleasant Station. — P, Lambertville, N. J.
4. BRIEF STATEMENT OF FORMER VIEWS.
5. GENERAL DISCUSSION. Origin of the Triassic Estuaries and Cause of Trap Eruptions; Origin and Deposition of the Strata; Composition of the Trap; Relations of the Trap and Sandstone; Review of Previous Ideas; Test-Characters for Intruded and Overflow Sheets; Examples of these elsewhere; Dikes; Intrusions; Overflows; Amygdaloids; Effect of Trap on Sandstones; Tilting; Theories to account for the Monoclinal Structure; Faults; Folds.
6. SUMMARY.

1. INTRODUCTORY.

SINCE seeing in 1877 the trap conglomerate on the back of Mount Tom, I have doubted the generally accepted explanation of the intrusive origin of the Triassic traps, and inclined to Hitchcock's theory of their origin by overflow contemporaneous with the deposit of the sandstone. During the past summer the desired opportunity came to examine the question further, by personal observation, in Massachusetts, Connecticut, and New Jersey, as detailed below, and with the result of satisfying myself that both views are correct; that some of the trap sheets are of intrusive, and some of overflow origin. The Palisade range along the Hudson may be taken as the type of the first, as has been shown by Russell; Mount Tom in Massachusetts represents the second, as was shown by Hitchcock. Other examples will be found below.

My endeavor has been to discover critical points that give decisive evidence one way or the other as to the origin of the trap sheets, so as to compel instead of merely allowing an explanation; but observations satisfactory or compulsory to one observer are not always so to another, and I cannot, therefore, expect that what has convinced me will surely be equally convincing to those who have thought differently; but to those who agree with my conclusions, as well as to those who differ from them, I would quote the wish of the elder Silliman : " I take the liberty to request, that those who may have it in their power will make precise observations upon the appearances at the junctions, ... accompanied by drawings and specimens when it is convenient ; and at least with accurate descriptions. We might thus be in a condition to form a general opinion of the origin of our trap rocks." *

2. LITERATURE.

A number of unimportant references to the Triassic rocks in Annual Reports of State Surveys are omitted in the following list. These can easily be found, if desired, by following Prime's "Catalogue of Official Reports," etc., in the Trans. Amer. Inst. Mining Engineers, VII., 1879, 455. Papers referring only to fossils and date of the deposits are also omitted, as the question of the age of the strata, for which the generally accepted determination is adopted, does not now arise. References to the articles cited are made in the text below simply by page number if the author has but one title in the list ; by letter and page number, if several of his papers are given. Pages in parentheses after a title show that only those pages of the paper are devoted to the Triassic formation. Papers that have not been seen are marked with an asterisk.

Akerly, S.
The Geology of the Hudson River. New York, 1820, (25–39, 57–64), and section.

Alger, F. *See* **Jackson and Alger.**

Bailey, L. W., and Matthew, G. F.
Preliminary Report on the Geology of Southern New Brunswick. Canada Geol. Surv., 1870–71, (216–221).

Bailey, L. W., Matthew, G. F., and Ells, R. W.
Report on the Geology of Southern New Brunswick. Canada Geol. Surv., 1878–79, (21–23 D), maps and sections.

Bailey, L. W., Matthew, G. F., and Hartt, C. F.
Observations on the Geology of Southern New Brunswick. Fredericton, 1865, (123–125), map and sections.

Barratt, J.
On the Evidence of Congelation in the New Red Sandstone. Assoc. Amer. Geols. Proc., 1845, 26.

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* Amer. Journ. Sci., XVII., 1830, 131.

Bradley, F. H.

On a "Geological Chart of the United States," etc. A. J. S. [3], XII., 1876, (289).

Britton, N. L.

On the Geology of Richmond County, New York. N. Y. Acad. Sci. Ann., II., 1881, (168–170), map and sections.

Canada.

Atlas to Geology of Canada. Montreal, 1863.

Chapin, A. B.

Junction of Trap and Sandstone; Wallingford, Conn. A. J. S. [1], XXVII., 1835, 104–112.

Cleaveland, P.

An Elementary Treatise on Mineralogy and Geology. 2d Edition. Boston, 1822, (746, 759).

Clemson, T. G.

Notice of a Geological Examination of the Country between Fredericksburg and Winchester, in Virginia, including the Gold Region. Penn. Geol. Soc. Trans., I., 1835, (311–313).

Cook, G. H.

a. Geological Survey of New Jersey. Map of the Triassic Formations. 1867.

b. Geology of New Jersey. Newark, 1868, (173–238, 336–339).

c. Geological Survey of New Jersey. Annual Report for 1879. Trenton, 1879, (18–35).

d. Geological Survey of New Jersey. Geological Map of New Jersey. 1881.

Cook, G. H., and Smock, J. C.

Geological Survey of New Jersey. Report on the Clay Deposits, etc. Trenton, 1878, (170, 304–306).

Cooper, T.

On Volcanoes and Volcanic Substances, with a particular Reference to the Origin of the Rocks of the Floetz Trap Formation. A. J. S. [1], IV., 1822, (239–243).

Credner, H.

Geognostische Skizze der Umgegend von New York. Deutsch. Geol. Gesell. Zft., XVII., 1865, (392–394).

Dana, E. S.

a. Abstract of a Paper on the Trap Rocks of the Connecticut Valley. A. J. S. [3], VIII., 1874, 390–392.

b. Trap Rocks of the Connecticut Valley. Amer. Assoc. Proc., 1874, 45–47.

Dana, J. D.

a. Origin of the Grand Outline Features of the Earth. A. J. S. [2], III., 1847, (390–392).

b. Manual of Geology. Philadelphia, 1863, 1869, (21, 414–443).

c. The same. New York, 1876, 1880, (21, 403–423).

d. On the Geology of the New Haven Region, with special Reference to the Origin of some of its Topographical Features. Conn. Acad. Trans., II., 1871–73, (45–48).

e. On some Results of the Earth's Contraction from Cooling; Part IV. Igneous Ejections, Volcanoes. A. J. S. [3], VI., 1873, (104–113).

f. Notes on Percival's Observations on "Indurated Bitumen" in the Connecticut Trap. A. J. S. [3], XVI., 1878, 130–132.

g. (On Russell's "Physical History," etc.) A. J. S. [3], XVII., 1879, 328–330.

Dawson, J. W.

a. On the New Red Sandstone of Nova Scotia. Geol. Soc. Journ., IV., 1848, 50–59, map and sections.

b. Additional Notes on the Red Sandstones of Nova Scotia. Geol. Soc. Journ., VIII., 1852, 398–400.

c. On the Parallelism of the Rock Formations of Nova Scotia with those of other Parts of America. Amer. Assoc. Proc., X., 1856, (20, 21).

d. Acadian Geology. Edinburgh, 1855, (60–115).

e. The same. London. 2d Edition. 1868, (86–124).

f. Notes on the Geology of Prince Edward Island in the Gulf of St. Lawrence. Geol. Mag., IX., 1872, (203–205).

g. The Physical Geography of Prince Edward Island. Canad. Nat., VII., 1872, 342, 343.

h. Supplement to the Second Edition of Acadian Geology. London, 1878, (28–30).

Dawson, J. W., and Harrington, B. J.

Report on the Geological Structure and Mineral Resources of Prince Edward Island. Montreal, 1871, (13–21).

Eaton, A.

a. An Index to the Geology of the Northern States. Leicester, 1818, (31–35).

b. The same. 1820, (206–212, 215–221, 249–256).

c. A Geological Nomenclature for North America. Albany, 1828, (section).

Ells, R. W. *See* **Bailey, Matthew, and Ells.**

Emerson, B. K.

The Deerfield Dyke and its Minerals. A. J. S. [3], XXIV., 1882, (195, 196).

Emmons, E.

a. Notice of a Scientific Excursion (to Nova Scotia). A. J. S. [1], XXX., 1836, (334–338).

Emmons, E.

b. Agriculture of New York. Albany, 1846, I., (200, 201).

c. American Geology. Albany, 1854, (106–112).

d. Geological Report of the Midland Counties of North Carolina. New York, 1856, (227–342), map and sections.

e. The Chemical Constitution of certain Members of the Chatham Series in the Valley of Deep River, North Carolina. Amer. Assoc Proc., XII., 1858, 230–232.

Fontaine, W. M.

Notes on the Mesozoic Strata of Virginia. A. J. S. [3], XVII., 1879, 25–39, 151–157, 229–239.

Frazer, P., Jr.

a. Second Geological Survey of Pennsylvania. Report of Progress in the District of York and Adams Counties, etc. Harrisburg, 1876, map and sections.

b. The same. Report of Progress in the Counties of York, Adams, Cumberland, and Franklin. Harrisburg, 1877, map and sections.

c. The same. The Geology of Lancaster County. Harrisburg, 1880, with a volume of maps.

d. The Position of the American New Red Sandstone. Amer. Inst. Mining Engr. Trans., V., 1877, 494–501.

e. Regarding some Mesozoic Ores. Amer. Phil. Soc. Proc., XVI., 1877, 651–655.

f. The Mesozoic Sandstones of the Atlantic Slope. Amer. Nat., 1879, 284–292.

Gesner, A.

A Geological Map of Nova Scotia, with an accompanying Memoir [1843]. Geol. Soc. Proc., IV., 1846, (190).

Gibson, J. B.

Observations on the Trap Rocks of the Connewago Hills, ... Pa. [1820]. Amer. Phil. Soc., II., 1825, 156–166.

Harrington, B. J. *See* **Dawson and Harrington.**

Hartt, C. F. *See* **Bailey, Matthew, and Hartt.**

Hawes, G. W.

a. The Trap Rocks of the Connecticut Valley. A. J. S. [3], IX., 1875, 185–192.

b. On the Mineralogical Composition of the Normal Mesozoic Diabase upon the Atlantic Border. Washington Nat. Mus. Proc., 1881, 129–134.

Heinrich, O. J.

The Mesozoic Formation in Virginia. Amer. Inst. Mining Engr. Trans., VI., 1879, 227–274, map and sections.

Hitchcock, E.

a. Remarks on the Geology and Mineralogy of aSection of Massachusetts, on Connecticut River, with a Part of New Hampshire and Vermont. A. J. S. [1], I., 1818, 105–116, map and section.

b. A Sketch of the Geology, Mineralogy, and Scenery of the Regions contiguous to the River Connecticut, with a Geological Map, etc. A. J. S. [1], VI., 1823, (39–80), map and sections.

c. Miscellaneous Notices of Mineral Localities, with Geological Remarks. A. J. S. [1], XIV., 1828, (227, 228).

d. Report on the Geology, Mineralogy, Botany, and Zoölogy of Massachusetts. Amherst, 1833, (206–241, 404–439), map and sections.

e. Final Report on the Geology of Massachusetts. Amherst, 1841, (199–204, 434–531, 640–663), map and sections.

f. On the Trap Tufa or Volcanic Grit of the Connecticut Valley, etc. Assoc. Amer. Geols. Proc., 1844, 10, 11 ; A. J. S. [1], XLVII., 1844, 103, 104.

g. Description of several Sections measured across the Sandstone and Trap of the Connecticut River Valley in Massachusetts. Amer. Assoc. Proc., IX., 1855, 225–227.

h. Ichnology of New England. A Report on the Sandstone of the Connecticut Valley, especially its Fossil Footmarks. Boston, 1858, (5–23), map and sections.

Jackson, C. T.

a. Nature of Minerals accompanying Trap Dykes which intercept various Rocks. Assoc. Amer. Geols. Proc., 1845, (30, 31).

b. On the Coal Formation of Deep River, North Carolina. Boston Soc. Nat. Hist. Proc., VI., 1856–59, 30–34.

Jackson, C. T., and Alger, F.

a. A Description of the Mineralogy and Geology of Part of Nova Scotia. A. J. S. [1], XIV., 1828, 305–330 ; XV., (132–146), map and section.

b. Remarks on the Mineralogy and Geology of Nova Scotia. Amer. Acad. Mem., I., 1833, (219–287), map and section.

Kerr, W. C.

a. Observations on the Mesozoic of North Carolina. Amer. Assoc. Proc., 1874, 47–49.

b. Report on the Geological Survey of North Carolina. Raleigh, 1875, (141–147), map and sections.

Leconte, J.

Elements of Geology. New York, 1878, (439–447).

Lesley, J. P.

a. Manual of Coal and its Topography. Philadelphia, 1856, (132, 133).

* *b.* United States Railroad and Mining Register, Philadelphia.

Lieber, O. M.

Reports on the Geognostic Survey of South Carolina. Columbia, 1860, (19, 20), map.

Lyell, Sir C.

a. On the Fossil Footprints of Birds and Impressions of Rain-drops in the Valley of the Connecticut. Geol. Soc. Proc., III., 1842, 793–796.

b. Travels in North America. London, 1845, (I. 12, 13, 124–126, 252–256; II. 171, 172).

c. On the Structure and probable Age of the Coal Field of the James River, near Richmond, Virginia. Geol. Soc. Journ., III., 1847, 261–280.

d. A Second Visit to the United States. New York, 1849, (I. 211–217).

e. On Fossil Rain-marks of the Recent, Triassic, and Carboniferous Periods. Geol. Soc. Journ., VII., 1851, 238–247.

Macfarlane, J.

The Coal Regions of America. New York, 1873, (505–528).

Maclure, W.

a. Observations on the Geology of the United States, explanatory of a Geological Map. Amer. Phil. Soc. Trans., VI., (2), 1809, (417–421), map.

b. On the Geology of the United States of North America, etc. Philadelphia, 1817, and Amer. Phil. Soc. Trans., I., 1818, (11, 12, 27–31, 63, 64, 66, etc.), with map.

Martin, B. N.

(On the Trapoid Rocks of the Palisades.) N. Y. Lyceum Proc., I., 1870–71, 132, 133.

Mather, W. W.

Geology of New York. Part I., comprising Geology of the First Geological District. Albany, 1843, (278–294), and sections.

Matthew, G. F. *See* **Bailey and Matthew.**

Mitchell, E.

Elements of Geology, with an Outline of the Geology of North Carolina. 1842, (36–39, 130–134).

Newberry, J. S.

Genesis of Sandstones. N. Y. Lyceum Proc., I., 1870–71, 131.

Olmsted, D.

a. Red Sandstone Formation of North Carolina. A. J. S. [1], II., 1819, 175, 176.

* *b.* Report on the Geology of North Carolina. 1824, 1825.

c. [Review of *b.*] A. J. S. [1], XIV., 1828, (236).

Peirce, J.

Account of the Geology, Mineralogy, Scenery, etc. of the Secondary Region of New York and New Jersey, and the adjacent States. A. J. S. [1], II., 1819, 181–199.

Percival, J. G.

Report on the Geology of the State of Connecticut. New Haven, 1842, (10, 11, 299–452), and map.

Prime, F., Jr.

Second Geological Survey of Pennsylvania. Report of Progress on . . . . Lehigh County. Harrisburg, 1875, (4, D).

Rogers, H. D.

a. Report on the Geological Survey of the State of New Jersey. Philadelphia, 1836, (145–170).

b. Third Annual Report on the Geological Survey of the State of Pennsylvania. Harrisburg, 1839, (18–23).

c. Description of the Geology of the State of New Jersey. Philadelphia, 1840, (114–171), map and sections.

d. (Oblique Deposition of the Triassic Strata.) Assoc. Amer. Geols. Proc., 1842, 25.

e. (Origin of the Crescent Form of the Triassic Dykes.) A. J. S., XLV., 1843, 333.

f. Address. Assoc. Amer. Geols., 1844, (27–31).

g. The Geology of Pennsylvania. 1858, (II. 666–697, 759–765), map and sections.

Rogers, W. B.

a. Report of the Geological Reconnaissance of the State of Virginia. Philadelphia, 1826, (52–62), and section.

b. Report of the Progress of the Geological Survey of the State of Virginia for 1839. Richmond, 1840, (69–83).

c. (Oblique Deposition of the Triassic Strata.) Assoc. Amer. Geols. Proc., 1842, 26, 27, 28.

d. On the Age of the Coal Rocks of Eastern Virginia. Assoc. Amer. Geols. Proc., 1843, 298–316.

e. On the Relations of the New Red Sandstone of the Connecticut Valley and the Coal-bearing Rocks of Eastern Virginia and North Carolina. Boston Soc. Nat. Hist. Proc., V., 1856, 14–18, 189, 190.

Russell, I. C.

a. On the Intrusive Nature of the Triassic Trap Sheets of New Jersey. A. J. S. [3], XV., 1878, 277–280.

b. On the Occurrence of Solid Hydrocarbons in the Eruptive Rocks of New Jersey. A. J. S. [3], XVI., 1878, 112–114.

c. The Physical History of the Triassic Formation in New Jersey and the Connecticut Valley. N. Y. Acad. Sci. Ann., I., 1878, 220–254.

d. On the Geology of Hudson County, New Jersey. N. Y. Acad. Sci. Ann., II., 1880, 27–80.

Schweitzer, P.

a. Notes on Felsites of the Palisade Range. Amer. Chemist, II., 1871, 23–25.

b. Analyses of Newark Sandstone. N. Y. Lyceum Proc., I., 1873, 136.

c. Analyses of Sandstones from New Jersey. N. Y. Lyceum Proc., I., 1873, 196.

Schweitzer, P.

d. Notes on the Felsites of the Palisade Range. N. Y. Lyceum Proc., I., 1873, 244–252.

Shepard, C. U.

On the supposed Tadpole-Nests, or Imprints made by the Batrachoides nidificans (Hitchcock), in the Red Shale of the New Red Sandstone of South Hadley, Mass. A. J. S. [2], XLIII., 1867, 99–104.

Silliman, B.

a. Sketch of the Mineralogy of the Town of New Haven. Conn. Acad. Sci. Mem., I., 1810, (87–95).

b. Mineralogical and Geological Observations on New Haven and its Vicinity. Bruce's Amer. Min. Journ., I., 1814, 139–149.

c. Sketches of a Tour in the Counties of New Haven and Litchfield, in Connecticut, with Notices of the Geology, etc. A. J. S. [1], II., 1820, (202, 203, 231–233).

d. Tour between Hartford and Quebec. 2d Edition. New Haven, 1824, (17–30, 428–431).

e. Igneous Origin of some Trap Rocks. A. J. S. [1], XVII., 1830, 119–132.

Silliman, B., Jr.

a. (Trap Eruption causing Upheaval.) Assoc. Amer. Geols. Proc., 1842, 64.

b. Report on the Intrusive Trap of the New Red Sandstone of Connecticut. Assoc. Amer. Geols. Proc., 1844, 14, 15.

Smith, A.

On the Watercourses and the Alluvial and Rock Formations of the Connecticut River Valley. A. J. S. [1], XXII., 1832, 218–231.

Smock, J. C. *See* **Cook and Smock.**

Taylor, R. C.

a. Memoir of a Section passing through the Bituminous Coal Field near Richmond, in Virginia. Penn. Geol. Soc. Trans., I., 1835, 275–294, with sections.

b. Review of Geological Phenomena, and the Deductions derivable therefrom, in two hundred and fifty Miles of Sections in Parts of Virginia and Maryland. Penn. Geol. Soc. Trans., I., 1835, 314–325.

Tuomey, M.

Report on the Geology of South Carolina. Columbia, 1848, (48, 65–67, 103, 104, 113), and map.

Tyson, P. T.

First Report of Philip T. Tyson, State Agricultural Chemist. Annapolis, 1860, (41), map.

Verrill, A. E.

Grand Manan. Appendix (E) in Dawson's Acadian Geology, 1878, 679, 680.

Walling, H. F.
Some Indications of Recent Sensitiveness to Unequal Pressures in the Earth's Crust. Amer. Assoc. Proc., XXVII., 1878, 190–197.

Whelpley, J. D.
Trap and Sandstone of the Connecticut Valley, — Theory of their Relation. Assoc. Amer. Geols. Proc., 1845, 61–64.

Wurtz, H.
Progress of an Investigation of the Structure and Lithology of the Hudson River Palisades. N. Y. Lyceum Proc., I., 1870–71, 99–105.

3. OBSERVATIONS.

The following observations were made in the summer of 1882. The attempt has been made in recording them to keep inference distinct from observed fact, though the two may come in the same sentence. The observations have been reduced as far as possible to graphic form, for ease of reading as well as for the convenience of those who may care to repeat them. It should be remembered that they are mostly the work of short excursions, made with the object of discovering the position and condition of the rocks only at certain points, and not with any idea of preparing complete geological maps of a district. The plans are generally traced from topographical or geological maps; none of the sections are constructed accurately, but all are kept down near natural proportions. In order to avoid too much assumption in these sections, all lines of contact not directly seen are drawn broken-dotted (—·—·—); the Hanging Hills section is an accidental exception to this rule. The scales of maps and sections are only approximate. The observations are referred to in the text farther on by the letters at their headings.

Nomenclature. — The trap ranges are grouped according to Percival's method: the largest of a system is called the *main range;* lateral ranges on the outcrop side or face of the main range are called *anterior;* on the back or dip side, *posterior.* These lateral ranges are numbered according to their distance from the main range. In the case of overflows, these terms have the unforeseen advantage of serving to denote the relative dates of eruption. *Upper* and *lower contacts* are between the trap and the overlying and underlying sandstones. *Dike* (except in quotations) is restricted to masses of igneous rock clearly of later date than the rocks they intersect, and with a greater extension across the layers of sandstone than parallel to them. *Sheet* is applied to interbedded masses of trap, of intrusive or of overflow origin. *Sandstone* is sometimes used in a general sense, applying to the whole formation, and is then not closely limited to its lithological meaning. *Bearings* are all magnetic. *Page references* to previous writings are made in parentheses after the author's name; the titles are given in the list above.

A. *Turner's Falls, Mass.* (figs. 32, 33, 34). — This manufacturing town is on a corner of land on the left bank of the Connecticut, which here makes a considerable detour from its usual course, and on the way exposes an excellent continuous section of sandstones and trap for more than a mile. This is best examined by beginning on the northwestern bank, one eighth of a mile below the lower suspension bridge (A, fig. 32), where the back of the main trap range is clearly seen. This range has its beginning on the southwest flank of Mount Toby in Sunderland, in a layer of trap making an inconspicuous ridge; Hitchcock has described its upper contact with sandstone in a brook a mile and a half southeast of Sunderland. It then advances northwest, and ascends on the back of Deerfield Mountain, gaining the summit a few miles before the Deerfield River cuts through the ridge to the Connecticut; two railroads pass through this gorge and cut the trap, but do not, so far as I could see in passing, show any contacts. East of Greenfield the Poet's Seat is the culminating point; here the ridge is doubled, with a shallow valley along its top, probably indicating a bed of sandstone or tufa, or a strike fault. It is the upper surface of this main trap sheet that comes to the river's edge below Turner's Falls (A, fig. 32); and going up stream the bright red shaly sandstone is soon met lying upon its vesicular, amygdaloidal surface, quite conformable to its slight irregularities, and showing no signs of local baking at the junction, or of any branching intrusions from the trap below. The sandstone strikes N. 65° E., dips 35° S. E. throughout the section. Following up the bank, we pass obliquely across the strike of the sandstone, and just before coming to the bridge reach the first posterior trap (B). The contact is unfortunately hidden here; it might be found by searching on the face of this posterior ridge farther northeast. The trap is at first dense, but a little beyond the bridge becomes vesicular, and so continues up to the entrance of Fall River. Looking southwest across the river, one may see an outcrop of rocks about in line with the strike of this trap, but they seem to be bedded; no ridge is visible in that direction, and I believe the trap ends about where the river crosses it. Going up stream the trap is seen continuously except in two places where covered by sandstone: the first is in a little hollow on its back (C), about one third of the way to the mouth of Fall River, where the bedding of the sandstone is somewhat uneven, but not more so, I imagined, than would result from the washing in of sand and mud to fill an irregular hollow; this exposure is about twenty feet square; the second is a much larger triangular patch of sandstone (D) at the mouth of Fall River, giving excellent contact specimens, very little weathered, retaining the usual texture, softness and color of the sandstone directly to the trap surface, and holding small scraps of trap clearly separated from the mass below (see fig. 34). A wooden dam gives passage across Fall River near its mouth, and directly opposite (S. E.) there is a small exposure of sandstone overlaid by trap breccia, with contact hidden. Farther up this valley, by climbing up its steep southeast bank opposite a road bridge, a larger exposure (E) is found some eighty feet over the stream. The sandstone is gray and micaceous, and dips a little steeper than usual; its contact with the igneous rocks is hidden, but after a blank of say five feet there is a bank of tufa containing fragments of hard trap. The tufa is deeply weathered, so that I could get no good specimen with fresh surface; it shows parallel lines on its weathered front, which seem to indicate bedding, as they were conformable with the sandstone strata below. The trap fragments here are round or oval, not angular as by the dam; some are as much as two feet in diameter, with a hard, dense surface, but vesicular within; they may be volcanic bombs. Twenty to thirty feet will probably cover the thickness of this tufa bed; next comes the dense trap of the second posterior range, well exposed at its southern end in a rocky point on the river bank; passing around this, we come to the third exposure (F) of overlying sandstone, showing the same features as the first. This trap also is not apparent as a ridge farther southwest, but points to a sandstone island in the river, and may, like the first posterior ridge, end about where the river cuts it. From here up to the falls, one fourth of a mile, beds of shale, sandstone, and conglomerate are well exposed in ascending section, but no more trap appears. The close conformity of the trap and sandstone throughout this series is noticeable.

This section is described and figured by Hitchcock (*d*, 423; *e*, 653, here copied, fig. 7). Numerous specimens of foot-prints have been found in the neighborhood. Emerson's recent article on the Deerfield Dyke and its minerals appeared after the above description was written: it confirms the overflow origin of the trap, but speaks of only two trap ridges, and regards these as originally one, now separated by a fault in the Fall River valley. I do not consider the evidence offered in favor of this view as fully excluding the idea of separate overflows of limited area, as above suggested; although, so far as the origin of the trap is concerned, it is immaterial whether the ridges are regarded as a single sheet faulted or as separate sheets.

B. *Mount Tom, Mass.* (figs. 35, 36, 37). — This section is one of the best I have seen. The following description is reversed from the descending order in which the observations were made. The bench on the western face of the mountain below the talus of trap fragments is dependent on a hard sandstone conglomerate; it forms a ridge by itself from the southern end of Tom over two miles to Rock Valley, where it dies away. The rock quarried at Mount Tom Station, Connecticut River Railroad, seems to be of the same horizon. From this bench the sandstone is generally hidden by trap blocks; but about three quarters of a mile north of the end of Mount Tom, there is a small exposure of sandstone in contact with the great trap cover; others doubtless occur, but on finding this one I searched no farther. The sandstone here, a few feet from the trap, is gray, micaceous, and clearly bedded; but near and at the contact it is dense, as hard as quartzite, bluish, and somewhat like the trap itself in appearance, with only the larger bedding-joints remaining. The two rocks are not welded together here: an open seam separates them, so that no single specimen shows both. The trap is dark, dense, fine-grained, and excessively hard; it lies evenly on the layers below without cutting them; the columnar structure does not show for some ten feet higher. Along the mountain summit the texture of the rock is much coarser, the crystals are occasionally a tenth of an inch in length. Descending the long eastern slope by a wood road, there was no clear evidence of any persistent variation in form, such as occurs by the Poet's Seat in Greenfield, or on the back of the First Mountain, south of Paterson, N. J. The entire mountain seems to be a single heavy trap sheet, several hundred feet thick. When nearly at the bottom of the valley, between the main and the posterior range, an excellent series of exposures was found in a little gully leading down the slope. First there was a glaciated surface of firm trap. Descending a little farther (*ascending* in the geological series), there was found some forty feet of ragged, rough surface, in part trap, and in part clearly a mixture of angular trap fragments with sandstone. The surface of the trap is often vesicular, and in places shows included fragments of a denser kind. The sandstone is reddish, not nearly so hard as that found on the western face of Mount Tom, though harder than some of the soft fragments of trap, which weather out leaving a rough framework of sandstone; at some points the bedding can be seen, but exposures are generally too small and rusty for this. The trap fragments in the sandstone vary from small grains up to pieces one to three inches in diameter; some are dense, some vesicular. This locality is about one fourth of a mile north of a strong gap in the posterior ridge, and is marked by a five-foot boulder of light granite. Crossing the marshy stream, a small outcrop of ordinary normal sandstone is seen on the opposite slope; similar outcrops are found one fourth of a mile farther northeast, higher up on the face of the posterior ridge; and finally, just below its trap, several feet of well metamorphosed sandstone appear, gray in color and quartzitic in texture. The trap here shows nothing peculiar. Crossing over the ridge and descending a quarter of the way to the river, we leave the trap and come to numerous outcrops of conglomeratic sandstone, darker in color than usual, and containing plentiful scraps of trap, many of them vesicular, and in size up to three inches. The first of these outcrops is not more than fifteen or twenty feet over the trap; many others appear at a greater distance, even on the railroad a little below Smith's Ferry Station. It was there that I first saw them in 1877, in company with Professor N. S. Shaler and Mr. J. S. Diller.

The upper contact was not found among these outcrops, but it is excellently shown in Delany's Quarry, on the railroad and river bank, not quite half-way from Smith's Ferry to Holyoke. (From the quarry to Holyoke Station is about an hour's tiresome walk along the hot, sandy track.) Here the rock is freshly worked, and the upper surface of the trap is well shown to be very amygdaloidal, uneven, and knobby, as a lava flow might be, and upon it lies the fine dull dark reddish muddy shale, fitting closely to the trap and filling up its inequalities, so that the sandstone a few feet higher is evenly bedded (see fig. 37). This contact shale is as soft as ordinary shale at a distance from the trap; it is easily scratched to powder with a knife. On some trap faces patches of similar shale appear to be included in the trap, but as they also are not metamorphosed, I consider them to be muddy fillings of cavities near the rough old lava surface, reached by passages not now exposed to view; where their bedding shows, it is about parallel to that of the sandstone above. There was no appearance of branching intrusion into the sandstone, or of breaking across its layers. I looked carefully at a great number of freshly exposed amygdules here and elsewhere, in hopes of finding some of them banded like those at Brighton, Mass. (see Boston Soc. Nat. Hist. Proc., XX., 1880, 426), but was always unsuccessful. Ten or fifteen feet of sandstone over the trap are well shown in the quarry. Several layers contain distinct fragments of trap, rather angular in form, and variable in structure from dense to vesicular. These layers are darker than the normal red sandstone, some being nearly black, presumably on account of the trap sand they contain; some might be mistaken for metamorphosed sandstone, as they have faint bedding, and in a rough way resemble trap; but they grade into normal reddish sandstone below as well as above, and this clearly shows that their color is not due to metamorphic action. There is a strongly slickensided joint at right angles to the dip in this quarry, with some evidence of a fault of several feet throw.

Hitchcock wrote (*e*, 442) that a tufaceous conglomerate "reposes on the greenstone on the east side of Mounts Tom and Holyoke; and consists of a mixture of angular and rounded masses of trap and sandstone, with a cement of the same materials. . . . I do not doubt but the same rock may be found on the east side of nearly all the greenstone ranges in the Connecticut Valley. Its thickness is but small, and it graduates on one side into greenstone, and on the other into sandstone." This evidently refers to a bed similar to those above described, and points to the same conclusion. He refers to it again in the Ichnology (*h*, 17). Lyell (*a*, 794) visited this region in his company, and concluded "that there were eruptions of trap accompanied by upheaval and partial denudation, during the deposition of the red sandstone." Dana quoted Hitchcock's results in 1863, and added, "But after an examination of the region the author regards it more probable that the appearance of scoria is owing to an escape of steam laterally from between the opened strata during the ejection of the trap of the adjoining mountain." (*b*, 430.) Emerson's observations, made recently (196), confirm Hitchcock's and those of the present writer. In his last edition of the Manual (1880), Dana makes no mention of overflows.

C. *West Springfield, Mass.* (fig. 38). — About two miles west of this station on the Boston and Albany Railroad, the track passes through a short cut in the second posterior trap ridge near its end on the north bank of the Westfield River, and fortunately reveals some twenty feet of sandstone below the trap, as may be seen even from a passing train. The natural outcrops in this neighborhood are very poor, as the ridge is almost smothered in the high sand plain of the Connecticut River. The main ridge and the first posterior are also very poorly shown as far as critical outcrops are concerned, though the trap itself is well opened in the city quarry by the railroad on the west face of the main ridge, where distinct columnar structure is apparent. In the railroad cut, it is noticeable that the hardness of the lower sandstone does not depend entirely on its distance from the trap, but rather on its composition. A sandstone stratum, some twenty-five feet below the contact, is red and very hard; then comes some softer red shales; above these some soft gray shales, and finally, next to the trap, several feet of hard red sandstone. The strata strike N. 25° E.; dip 20°, E. S. E. The two rocks here are very firmly welded together at their junction; the line is slightly irregular, but its average conforms precisely with the bedding. Within a foot of the contact, the sandstone is somewhat vesicular; within an inch, its color changes to light gray, and in texture it becomes a firm dense quartzite. The adjoining trap is dark and dense, and but slightly amygdaloidal. The rest of the cut is all in trap, but the rock is by no means of uniform structure. There is first a mass from twenty-five to thirty feet thick (at right angles to dip), of which the greater part is ordinary dense trap; but its upper six to eight feet become very amygdaloidal and loose-textured, and the upper limiting line, clearly seen on both sides of the cut, dips closely parallel to the sandstone strata; near the bottom of the cut it exhibits some irregularity. Over this, but separated by an open seam, comes a second mass of dense trap, of about the same thickness as the first. This is not so decidedly amygdaloidal as the first in its upper part, and is limited above by a very even six-inch band of coarsely crystalline trap, distinctly visible on both sides of the cut. Ten feet higher, there is another coarsely crystalline band, four inches thick, then say eight feet of massive trap overlaid by drift; no upper sandstone could be found. These even persistent bands dip parallel to the sandstone; they are rather abruptly interpolated in the trap, and the whole is firmly welded together. I do not feel satisfied with any suggestion yet presented in explanation of them; but there can be little doubt that the lower mass with its amygdaloidal cover is a single lava flow, buried under later eruptions. One can hardly imagine a clearer example of the kind. A number of small faults can be seen on the sides of the cut, well marked by a foot or so of brecciated trap; the fault planes are all at right angles to the dip of the sandstone; the largest throw was only a foot, with uplift on the east.

I have been unable to connect the ridges here with the single posterior range by Mount Tom, and cannot say how they are related to one another.

D. *Beckley, Conn.* (fig. 39). — The several curved ridges shown on Percival's map (1, 2, 3, north end of E. III.) in the towns of Berlin and

Wethersfield, give clear explanation of the two causes that have produced the crescentic outlines so characteristic of the trap. The first (1) is shown to be a flat fold, a faint canoe-synclinal outcropping to the north and west, by the close parallelism of the sandstone ledges around its front; their strike changes so as to run parallel to the trap bluff, and they dip towards and under it on three sides. The trap shows a steep face on the convex, and a long gentle slope on the concave side of its crescent. It is undoubtedly a thin overflow sheet; for although no contacts were seen, normal red sandstone was found three feet below the trap, and red shaly sandstone fifteen feet above it, on a cross-road a quarter of a mile southwest of Beckley Station; and the trap is compact at the bottom, and very loose and amygdaloidal on top. Evidently, then, the sandstones and the trap have been here slightly folded together, and erosion has revealed their canoe-form precisely as it has brought out the greater canoes of Medina Sandstone in Pennsylvania. The eastern side of the canoe is not visible except at its northern end, or bow as it may be called, because the fold is canted over on the east. The fold as a whole has a gentle eastward dip.

The second curve (2) is made of trap much like that of the first, and it is very probably the same trap sheet brought to the surface again by a north and south fault with upthrow of forty or fifty feet on the east; its curve does not seem to depend on a fold, but simply on the cross valley of the Mattabesic; for a stream cutting through a monoclinal ridge always produces such a retreat in the outcrop line of its determining hard stratum. The second and third crescents are therefore to be regarded as parts of a single fold, cut into the imitation of a double fold by the stream between them.

It becomes, therefore, an important matter to determine which of the crescentic ridges shown in Percival's and other maps are due to folding of the trap sheets, and which to erosion without folding; E. I. and E. II. are undoubtedly folds; so is the great curve of E. IV. that runs up into Massachusetts. New Jersey shows several others. But the peculiar forms of E. IV. 1, 2, 3, are chiefly, if not entirely, due to erosion, as is shown under the next heading.

Percival gives a close description of the facts about Beckley (358), but makes no statement of their cause.

E. *Meriden, Conn.* (figs. 40 – 43). — Two days' walking about the Hanging Hills and Lamentation Mountain failed to discover any contacts, very probably on account of keeping mostly to the roads so as to cover more ground, for the work here was chiefly stratigraphical.

The main result found was that the Hanging Hills and the neighboring trap masses marked on Percival's Map, E. IV. 1, 2, 3, 4, 5, and probably 6, and others farther north, are all parts of a single trap sheet of overflow origin, broadly and faintly folded into a very flat synclinal, perhaps a little faulted, and deeply cut by erosion around the margin. It is pretty surely an overflow, because it has small influence on the sandstone when the two are seen near together, and its upper part is very amygdaloidal; and because it makes part of the Mount Tom range, whose overflow origin is well established. The former union of the now separate hills is made sufficiently sure by the nearly uniform height of the hills on the opposite sides of a gap (see section, fig. 41); by the uniform slope in a single plane of the separated parts of the sheet (fig. 40); by the conformity of this slope to the dip of the adjoining sandstone, wherever seen; and by the regular position of the first anterior ridge on the slope below the great bluffs. This is not apparent from Percival's description or map; on the latter, his outlines indicate only the ridges or elevations, not the areas of trap. Professor Dana's reduced copy of this part of the map (*c*, 418) unites the hills as here drawn, but he regards their trap as an intruded sheet (*d*, 41). West Peak (E. IV. 3), the highest of the Hanging Hills, owes its height over 2 and 4 to being at the southwestern end of the flat synclinal; to the same structure is due the change in the direction of the bluffs at this high point from a north and south to an east and west line. E. IV. 5 is higher than 4 chiefly because it is farther from the axis of the synclinal; it is noteworthy that the oblique gaps between 3 and 4, 4 and 5, etc., are about parallel to this synclinal axis, and may very probably indicate the position of subordinate bends or breaks.

I believe it probable and provable that Lamentation Mountain (E. III. 5) is a reappearance by faulting of the Hanging Hills overflow sheet, and it may extend even through E. III, II, and I, as is explained below under faults and folds.

F. *Wallingford, Conn.* (fig. 45). — The sandstone in this neighborhood is loose and coarse, with well-marked cross-bedding; it is cut by many dikes, as was first stated by Chapin in 1835, but there are also several sheets nearly conformable to the bedding. The dikes are well seen on the road to Cheshire, half a mile or more southwest of the Wallingford Station (New Haven and Hartford Railroad), where they break through the sandstone very irregularly: they are from five to twenty feet thick, but do not affect the adjoining sandstone for more than a few inches. Fig. 45 shows the ragged edge of one of them.

Besides the dikes, there are sheets of trap cutting the sandstone at a small angle, or perhaps in places conformable to the bedding. One of these begins close to the corner of the Middle Turnpike and the Cheshire road, and can be easily followed several hundred feet obliquely up the slope to the northwest; it makes a little bench on the hillside, rendered clearer by some quarrying work at several points; it is about fifteen feet thick, dense throughout, and its columns are closely at right angles to its bounding surfaces; the sandstone is baked for a few inches below it, and the only sandstone found on its back was hardened. Another similar bench is seen a little higher; and a third makes a well-formed *mesa* near by, locally known as Mount Tom. All of these are probably intrusions; but they have not the regular vertical position shown in Chapin's general section (see fig. 8). The trap here is more irregularly intruded than at any other place I have visited.

G. *New Haven, Conn.* — There is a good exposure of sandstone on the southwestern face of West Rock under the trap. The strata here are of coarse granitic sand, and red and purple shales; sometimes firm, but with several purple shaly beds; they do not show so much metamorphism as the rocks beneath the Palisades, but nevertheless appear to be distinctly changed from their original condition for several feet from the trap, thus gaining a compact crystalline texture in certain layers. The trap is fine at the base, where it is conformable to the sandstone, and very compact through the whole mass: no amygdaloid was seen at any point on the face or back.

The eastern slope near the southern end of the Rock is covered by shaly sandstone for a considerable distance toward the top; it is often exposed in little gullies, and shows a variety of colors from gray to purple and bright brick-red. But for several hundred feet beyond the uppermost exposure, no rock is seen till the firm trap appears; at least such is the case on the path leading up to the "Judges' Cave," * and along several gullies farther south. Undoubtedly a junction may be found by searching farther to the north. In the covered space, several fragments were found resembling baked shale; they are probably from nearer the junction.

Pine and Mill Rocks are simply large dikes of compact trap, about vertical, cutting across nearly horizontal granitic sandstones; a marked consolidation has been produced by their heat for ten or twelve feet at least from their sides. Their width and direction are variable: the former is certainly as much as two hundred feet at some points; and their general trend is east. A rough but distinct columnar structure is seen at right angles to the sides. Their junction with the sandstone is somewhat irregular; but this is natural, as the latter has no well-marked joint planes.

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* A rude shelter under some boulders, where "Cromwell's Judges" were concealed for a time.

East Rock shows two patches of lower sandstone on its southwestern face; they are very similar to that described under West Rock, except that about eight feet below the conformable junction, a spotted appearance has been produced in a layer of purplish granitic sandstone. The trap is also like that of West Rock. Ascending by the road on the southern side of the hill, and when the eastern slope is reached turning across a field into the wood, a very strongly baked granitic sandstone is found within a few feet of the fine compact trap: the sandstone is very dense and much more crystalline than any found elsewhere in the Connecticut valley, but it rapidly loses this character, and becomes soft and fragile farther down the hill, like that found on the back of West Rock.

A number of dikes (fig. 44) may be found by crossing the river from New Haven by Tomlinson Bridge, and continuing half a mile along Forbes Avenue toward East Haven. These were long ago described by Hitchcock (*b*, 56), but his figure (here copied, fig. 2) makes them much too regular; they vary in strike and dip as well as in thickness, and their sides are uneven. They are not at all amygdaloidal; their baking extends one or two feet into the adjoining granitoid sandstone. The second cut on the Shore Line Railroad east of Fair Haven shows a similar dike; but the third cut is in a coarse granitic sandstone that makes a strong ridge by itself, being hard enough to stand up between the softer shaly sandstones on either side, though not visibly aided by any igneous rock. The ridge west of Saltonstall's Lake (Percival's E. I.) is cut at a low gap by the same railroad, and shaly sandstones are exposed, conformably covered by trap, and baked to white quartzite immediately at the junction, as at West Springfield. The line of contact is broken at one point by a very small fault, displacing the shales and trap equally, and evidently of later date than the eruption. The trap is brecciated at certain points, and is generally uneven in its jointing, and its upper surface along the lake shore is very amygdaloidal. No overlying sandstone could be found.

There is fairly good evidence that the natural gap, cut deeper by the railroad, results from a transverse fault of ten or twenty feet, with the throw eastward on the southern side.

Reference to Percival's description of these ridges is given farther on. Professor Dana gives a brief mention of the traps of this district (*d*, 46; most of this article applies to the quaternary features of New Haven). E. S. Dana and Hawes describe the composition of the trap here and elsewhere, and note an increase in the hydration and alteration of the eastern traps over the western. (See below, under Composition of Trap.) All of the trap is regarded as intrusive by these authors.

From the descriptions given above, and a comparison of this region with others, I am led to believe that the Saltonstall Ridge is an overflow: its small metamorphic effect at the base, its decided amygdaloidal texture on the back or upper surface, its irregular and brecciated structure, and its alteration and hydration, all agree with the characters of overflow sheets rather than with those of well proven intrusions, such as East Rock and the Palisades.

Palisade Range. — H. *Fort Lee and Englewood, N. J.* — Sandstone shows at the water's edge above and below the wharf at Fort Lee. About eighty feet up the hill, under the Bluff Point House, a path cutting shows baked shales seven feet from the trap.* A two-mile walk northward from here leads one obliquely over the range toward Englewood, showing many well-glaciated knobs of coarse, dense trap on the way; the glacial striæ advance obliquely up the back of the range, bearing S. 20° E. A small stream known as Mill Brook, shown close to Floraville, a mile south of Englewood on the Triassic Map of New Jersey (Cook, *a*), gives a good exposure of the upper contact of sandstone on trap.†

The trap is of rather coarse texture when first shown in the stream; it is evenly divided by parallel joints, one to three feet apart, dipping 12° W. N. W., just as the sandstone dips farther on; the columnar structure is subordinate to this appearance of bedding. Following down the stream-bed, the texture soon becomes finer, but is nowhere vesicular, and in a short distance highly metamorphosed sandstones and shales are reached. Their bedding is very even, and not perceptibly disturbed near the trap; their color varies from nearly black to gray or greenish: in texture they are jaspery or distinctly crystalline. The junction was found with difficulty, and only after passing over it many times, up and down stream. It was at last discovered in a block, slightly moved from its original position by frosting and stream-work, but still preserving its joint faces parallel to those in the ledges near by. The ledge from which this block had been loosened was covered; but as trap in place was found two feet below it, and baked sandstone in place three feet above it, I have no doubt that it showed the true place of junction. Its weathered face showed no change of color, and very little change in texture, and specimens showing the actual welded contact were found only after much hammering. They closely resemble those found at the Weehawken tunnel at the under contact; in both cases the igneous rock is bluish black, dense, and fine, and for a quarter of an inch from the contact is chilled to a dark gray; and the aqueous rock is gray or dark, and the more distinctly crystalline of the two. The thickness of the Palisade Range trap between these contacts is, according to a true scale section by Cook (*b*, 200), about seven hundred feet. Some twenty feet of metamorphosed beds are seen farther down the brook; then exposures are rare. A hard reddish-white sandstone was found farther south lying say one hundred and fifty feet over the trap. No posterior ranges of trap are known in this district, unless the Snake Hills back of Hoboken are so called.

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* Contacts could certainly be found by further searching. The bluffs at Shady Side Landing, a few miles down the river, and under Englewood Hotel, two miles up stream, seemed worth visiting, as seen from a passing boat. Mather (282) gives examples of contacts farther north; some of his figures are here copied (figs. 11–14).

† Cook mentions sandstones overlying the trap at Englewood (*b*, 178, 208). I was directed to Mill Brook, as a stream likely to show the desired contact, by Mr. J. H. Serviss, of Englewood.

This excursion can easily be made in an afternoon from New York; going up the Hudson to Fort Lee by boat from Canal Street, and returning from Walton Station, Northern Railroad of New Jersey, to the Erie terminus. It is of value, as upper contacts are rare.

J. *Weehawken, N. J.* (fig. 46). — The several exposures of the sandstones below the trap in this district have been fully described by Russell (*d*); some of his figures are here copied (figs. 30, 31), and a more detailed view of the junction at the point of rocks below the Duel Ground* is added (fig. 46). H. Credner examined the Palisade trap in 1865, and pronounced it intrusive; he regarded the Snake Hills as a branch from the main "emporbrechende Dioritmasse" (393).

It is very probable that the advance of the Weehawken cliffs to the river bank at this point is due in part to the resistance to erosion offered by the chimney or dike of trap, which here descends close to the water's edge, while elsewhere the trap generally rests on a sandstone base, thirty to one hundred feet above the river; but it is also quite possible that a fault, similar to that seen at Garret Rock, Paterson (L), has aided the advance. The intersection of the sandy and shaly layers by the dense trap, and their metamorphism, are excellently shown. The branch dike cannot be traced quite to the greater mass, but they undoubtedly join below the talus; the branch is about four feet thick, generally lying evenly between the layers, but at one point crossing them in an irregular, ragged passage; it is clearly traced two hundred feet horizontally; and where it is lost to sight the main trap mass of the high cliffs above has risen nearly half this distance over it. All the bedded rocks here are thoroughly baked, and near the junctions are more or less clearly crystallized; their color varies from light gray to black, but there are no red beds; the beds above the branch dike are affected quite as stongly as those below it.

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* The Hamilton-Burr duel ground of 1804.

Half a mile farther north, where the tunnel of the West Shore road (New York, Lake Ontario, and Western Railroad) opens on Day's Point, another contact was found. Here the fine dense trap lay evenly on the baked and crystallized layers below it, of which some eight feet were shown; their color was dark or black, not red. This contact will probably be covered by later work. Day's Point, a low triangular projection into the Hudson, where the wharves of the West Shore Railroad are in process of construction, now shows a small ledge of sandstone, rapidly being cut away in the work of grading. It is separated from the trap by eighty or one hundred feet of sandstone, measured at right angles to the dip of 12°. The upper layers of the ledge are firm, fine-grained, and red; the lower are looser, clear white, with some coarser grains of transparent quartz. Similar white sandstone occurs under the cliffs a third of a mile southwest of the Duel Ground.

K. *Jersey City, N. J.* — The recent work of straightening the old cut on the Pennsylvania Railroad gives an excellent section with many fresh exposures through this lower part of the Palisade Range. The trap is generally coarse; in some small patches there were crystals of pyroxene half to three quarters of an inch in length. It was nowhere found to be the least vesicular. Broad joint faces are very common, and faulting has taken place on some of them. Near the eastern end of the cut there is a vein or dike, six inches wide, vertical, trending about north and south, in the trap. It is light gray in color and is composed of a fine granitoid mixture. Its texture is uniform throughout, and the trap shows no change of structure on approaching it. I have found no other example of the kind.

Both Cook (*b*, 216) and Russell (*d*, 43) give evidence to show the existence of a soft bed, probably of sandstone, between the eastern and western part of the trap. Its place in the cut is marked by an open hollow in which no rock is now to be seen, and it is not fully proven not to be a fault like that at Garret Rock, Paterson. There is a longitudinal valley on top of the Palisade Range at Fort Lee, but coarse trap is seen so plentifully on its two slopes that there is little room for sandstone at the bottom; and its cause is very probably a fault. Cook also notes that the trap of the Palisades is remarkably uniform and very hard (*b*, 178).

L. *Paterson and Little Falls, N. J.* (figs. 47, 48). — First and Second Mountains* are here cut through by the Passaic. The flat country back of the broad gap and the considerable quantity of drift in the neighborhood indicate that the present course of the river is not its course during preglacial times of greater land elevation. We cannot, therefore, now see the old valley bottoms, so that here, as on most of the Palisade Range, the back of the trap is stripped of its sandstone cover below the present general surface of the valley drift, and upper contacts cannot be found. In spite of the deep river gorges, and the large areas of trap exposure, I was unable, in searching a day and a half in this district, to find any sandstone lying on the trap; but lower contacts are seen at several points. The best of these is in the gorge below the Passaic Falls at Paterson: on the left bank the exposure is in a high bluff, not easily reached; on the right the trap is quarried for paving-blocks, and a fresh contact constantly shown and easily accessible (fig. 48).

There are red strata of firm sandstone and thin-bedded shale cut below the trap, and up to a few feet of the junction they show no marks of alteration; both can be matched closely at many points distant from any igneous rock. Within a foot of the contact the sandstone becomes firmer than usual, and shows rusty cavities, presumably a metamorphic effect, as they are most numerous by the trap. The upper half-inch of sandstone is darker than the rest but still reddish. The line of junction is easily found and traced; it is parallel to the sandstone layers, and nowhere cuts across them; the slight waving irregularity that it shows does not demand intrusion for its explanation. Specimens are easily broken out showing the two rocks welded together. The mass of the trap in the gorge is dark, fine, and even in texture; farther back from the sandstone it becomes coarser, but no samples were found so coarse as those from the Jersey City cut or from Goat Hill on the Delaware. Close to the junction, amygdaloidal cavities are very plenty; but most of them are within a foot or even half a foot of it, and here the trap is very fine-grained. The lower ten or fifteen feet of trap is of very heavy columns, two to four feet on a side, irregular or roughly rectangular; divided near the middle by rather continuous joints parallel to the sandstone bedding, sometimes breaking the rock into slabs two to ten inches thick. No change of texture is seen at these joints, and some of the columns are continued above and below. The heavy columns suddenly change upwards to smaller ones, six inches to a foot on a side, but there is no corresponding change in the texture of the rock, nor is there any appearance of a seam between the two parts; it is simply a change of jointing, for which I can suggest no satisfactory cause. The smaller columns are not all parallel, but incline in various directions; some variation is shown in the figure where they overhang the lower columns. Where thus irregular in position, they are at right angles to the present surface of the ground (noted also by Cook, *b*, 202, 203). The same change of structure is shown a third of a mile south, by Barber's Mills; again a little farther where the Delaware, Lackawanna, and Western Railroad cuts a bench for its passage around the end of First Mountain, here known as Garret Rock; and finally in the first and third of three quarries opened on the eastern face of the mountain, over the railroad station. Contacts of trap and sandstone show in all but the first of these, but not so clearly as at the Falls; the sandstone shows no effect of heat except the slight one above described. Of these latter localities the most important is that on the railroad (fig. 47), showing two strike faults of small throw. The eastern and greater of the two is covered by a ravine and its rubbish, but is proved by the repetition of shaly sandstone, heavy columns, and smaller columns on either side; from junction to junction measured along the track is one hundred and sixty paces, say four hundred and fifty feet; the junction line dips with the bedding 10°; this gives seventy or eighty feet for the displacement, with downthrow on the east. The second fault, a little farther west in the same cut, is shown to be about eight feet by the displacement of the upper surface of the heavy columns with downthrow to west; the fault is on an open joint, parallel to the columns, and striking with the ridge.

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* Called the Watchung Mountains in Cook's later Reports.

The mountain is most easily ascended by its northwest flank; from any of its higher knobs* a well-marked longitudinal valley is seen separating the eastern from the western summits; it extends several miles with varying distinctness, and is very marked at the Notch, where the

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* Most of these knobs are well rounded by glacial action, and some still retain striæ pointing directly up hill. Excellent scratches on the trap at Little Falls point up into Vernon Valley between the two mountains.

Greenwood Lake Railroad crosses the mountain. As the valley is in line with the larger fault, they probably stand in the relation of effect and cause; the throw has very probably increased where the valley is well formed.

Sandstone was not found in the valley as far south as the Notch, although the place is favorable for its preservation. If continued northward, the fault would pass east of the trap front at the Falls, and its effect, if existing there in the sandstone, would be less noticeable.

On the western foot of First Mountain two small exposures just west of the Morris Canal and south of the High Bridge showed amygdaloidal trap, and one of them presented clear marks of variation in structure bounded by curved surfaces, such as are found farther south at Feltville. There was also seen at this point a surface much like that of flowing lava or slag.

Sandstone is not seen in the flat valley until the village of Little Falls is reached, a short mile west of the First Mountain trap, where it is shown in normal condition in a quarry by the canal and river, about two hundred yards east of the Second Mountain trap. The right bank of the Passaic here approached gives no chance of finding a junction; but on the other side, a little farther down than opposite the quarry, there is a small opening in which fine trap and red sandstone both show, though the contact is hidden by several feet of rubbish. The sandstone has no marks of baking. Following up stream, the trap varies greatly in texture; an irregular very amygdaloidal mass grades into firm trap on one side, and into a much decomposed loose rock on the other; I have considered the latter an ash or tuff. The dense trap is often distinctly columnar, and above the canal bridge it is well divided by nearly horizontal open joints into sheets of varying thickness. In the midst of this there is a very uneven mass of amygdaloidal trap that seems to contain fragments. Farther west there is a broad area of flat alluvial meadow-land.

The trap of this region is described by Rogers (*c*, 146) and Cook (*b*, 179).

M. *Feltville, N. J.* (figs. 49, 50). — Mr. I. C. Russell (*a*) describes an upper contact in a little ravine on the back of First Mountain near this deserted village; but I failed to discover any outcrops corresponding closely to his description. My time there was short, and allowed only the examination of a ravine about an eighth of a mile east-northeast of the village; the stream from it enters the brook in Washington Valley at the lower part of an old broken dam. Going about one hundred yards from the mouth, so as to descend (geologically) below the trap surface, the rock appears firm and hard in the stream bed: shaly sandstone often outcrops on the banks of the ravine, but at no point within five feet of the trap, and generally ten or fifteen feet from it. Returning down stream, the trap becomes amygdaloidal, and shows rounded bosses or knobs similar to those described by Russell; but as seen here they are not directly at the upper surface of the trap. Nearly at the entrance of the ravine, a bank of much-weathered vesicular and fragmental trap suggests a trap breccia, but the surface is too much rusted for determination. The most important exposure here was found in the side of a short adit made some years ago on a small vein in the trap; it is known in the district as the "Copper Mine." It shows (fig. 49) a number of oval masses of trap, up to two feet or more in diameter, contained in a peculiar red and black matrix. The trap masses vary in their texture and color with the distance from their surface; the outer part is black and dense, then amygdaloidal for a few inches with concentric bands of color, and rather dense near the centre. The matrix (fig. 50 a, b) has all the appearance of being a disorderly mixture of small, angular scraps of trap, up to an inch long, held in a soft reddish shaly mass, that shows no signs whatever of metamorphism. Its contrast with the over-lying sandstones at Englewood is very marked, and it is difficult to understand how this could have been formed except on the surface of a pre-existent sheet of lava.

Russell says (*a*, 280), "The section at Feltville furnishes indisputable evidence that the igneous rocks composing the first Newark Mountain were intruded in a molten state between the layers of the stratified rocks subsequent to their consolidation." He describes (*b*) another upper surface of the trap on the back of the same mountain farther south, back of Plainfield, where there is "an amygdaloidal trap passing into a metamorphosed shale," so that it is frequently difficult to detect the difference between the two rocks. I was unable to visit this point.

Feltville can be reached by a pleasant walk of four miles from Fanwood Station, Central Railroad of New Jersey; the Triassic Map of New Jersey, 1867, gives the roads very clearly. It is to be hoped that further observations will soon be made to give evidence for one or the other of the above discordant conclusions. At Fanwood Station, the railroad cuts the unstratified terminal moraine of the quaternary ice sheet (New Jersey Geol. Survey, Annual Reports, 1877, 10; 1878, 16); and good specimens of foreign angular and scratched stones, large and small, are easily found.

N. *Martin's Dock, N. J.* (fig. 51). — Two beds of trap appear in the shales a little above Martin's Dock on the north (left) bank of the Raritan River about two miles below New Brunswick; they are therefore about three miles posterior to Palisades — Rocky Hill trap range, which if continuous is here buried under the cretaceous formation. The lower bed is about fifteen feet, the upper two feet thick, and they are separated by some ten inches of slate; the two are closely parallel to each other and to the strata of shale and sandstone below and above, and all dip ten to twelve degrees westerly; there is no appearance whatever of the traps cutting across the shaly layers that enclose them. The section may be described as follows, beginning at the bottom.

Soft, fragile shales, generally red in color, appear along the shore for several hundred feet down stream: occasionally they vary to a fine, sandy layer, six to twelve inches thick, with rather irregular layers, as if disturbed, although the shale below and above is very evenly bedded. Approaching the trap, three to five feet below it, the shale is grayish, but still soft and fissile; for six or eight inches below the trap, the shale becomes slaty, dark, tending to bluish black, and hard; but in places two or three inches under the junction occur loose, soft, weathered patches quite unlike the firm, dark shale enclosing them. The trap and shale are not welded together; all the junctions are separated by open joints, so that no specimen showing the two rocks together could be obtained. The lower heavy trap layer is firm, dense, dark throughout with finer texture at both junctions, and no appearance of vesicular structure; it breaks into rough columnar blocks, and where these are weathered on the shore, they often have the ragged look of a breccia, but no such structure could be found in the rock in place. The intermediate stratum is a hard black ringing slate: in places it shows a slight breaking and disarrangement of its layers, not by cross-faulting or any general disturbance, but more as if kneaded together. The upper trap layer is dark and dense, like the lower. Above it the rock is very rusty from weathering, and shows an open, loose texture for some six inches; the rusty color continues for several feet, and about ten feet from the trap there are normal soft red shales again.

These trap-sheets must be intrusive, although they show less baking than similar sheets on the Delaware. Cook says (*b*, 202), speaking of the bedded appearance of the trap here and elsewhere, "So strongly marked are these divisional planes, and so closely do they resemble marks of stratification and even lamination, that good observers are frequently unable to tell which is trap and which is only discolored shale." He includes this with the general occurrences of intrusive trap.

O. *Point Pleasant Station, Belvidere Railroad, N. J.* (fig. 52). — The main mass of trap here seems to be a small example of what is shown on a larger scale farther down the Delaware about Lambertville, but the smaller sheets resemble most the little outcrops at Martin's Dock, and are finely shown.

The first outcrops on the railroad are about five hundred feet below the station, where a dark, fine grained trap shows in the bank; it is faintly columnar, but clearly bed-jointed, so that the slabs dip 12° N. 20° W.; the sandstone wherever seen is closely of the same position. There are no amygdules, but on some weathered surfaces the trap is pitted in lines parallel to the bed-joints, showing points of chemical weakness probably determined early in its history. The rock rapidly becomes coarse-grained and light-colored on going northward, and in this form rises to the hill-top; on the slope where seen, it is not columnar, but breaks out in large masses and slabs; it becomes somewhat finer again, but I failed to find its northern limit, which occurs in a ravine. North a little farther and opposite the station is a bed of fine-grained dark trap, again showing distinct bed-joints and little cavities weathered in lines parallel to its lower surface; there is no apparent change of structure to cause them. This trap rests on a fine, brittle black slate; the junction of the two rocks is seen with few interruptions for a hundred feet, and is precisely conformable to the bedding. The upper surface of the trap was not seen; but judging by the form of the bank, the bed is not more than twenty feet thick.

A little above the station there is a cliff, thirty to fifty feet high, of fine black trap; its face is marked by joints a little steeper than a normal to the dip, and dividing the rock into sharp-edged columns (▱); there are other joints parallel to the bedding of the adjacent sandstone; and two four-inch bands of the same dip were traced some forty feet along the face, distinguished from the rest by a peculiar roughness of weathered surface dependent upon short cracks occupied by calcite. This may be called a kind of vesicular structure, but not at all like the ordinary trap amygdaloid. No contacts of this trap with slates were seen, but the slate where found above and below was fine, black, and brittle, and dipped 12° parallel to the bed-joints in the trap.

An eighth of a mile above the station, a dry stream bed gives a good series of exposures to a height of more than two hundred feet over the river. Much the greater part is on fine black shale or slate, or brownish shale of somewhat coarser texture; near the several trap sheets, it is always black and brittle. Mud-cracks were noticed on many loose slabs, and occasionally in place here and farther up the river. Four beds of fine black trap occur in this little ravine: the first two form a single shelf over which a fine thread of water falls (fig. 52), the lower bed being four feet thick, the upper twelve, with four to six inches of shaly slate between them. This parting of slate is seen between the two beds of trap, extending with uniform dip for seventy feet. The slate and trap are very much alike on fresh surfaces, but the slate has a bluish tinge, and shows some signs of breaking on its bedding; the trap is blacker, and its fracture is more conchoidal. Both are jointed into sharp-edged columns, but these are most distinct in the trap. Farther from the trap, the shaly structure is more apparent, and bands of lighter and darker color are sometimes found. The other two trap sheets make two small benches farther up the ravine, and show about the same characters as those just given, but their junctions with the slate could not be determined, so nearly alike were the textures of the two rocks near their contact, and so closely did joints in the trap imitate beds in the slate. Weathered fragments of trap often showed a pitted or scoriaceous surface, though no cause could be seen for this in the structure.

Returning to the railroad, and going north again, the same trap sheets are passed as they descend to cross the river. A quarter of a mile above the station, dark red sandstone appears in the bank, and continues without further interruption; it is fine and hard, though not at all quartzitic; generally thick-bedded, but sometimes shaly and mud-cracked; fine green dots of epidote (?) are found in it. It is very evident that the brittle black slate that adjoins the trap was never like this sandstone.

Rogers (*c*, 156) and Cook (*b*, 192) both refer briefly to this locality. The trap here is shown on the Triassic Map of 1867, but not on the Economic Map of 1881 (Cook, *a* and *d*).

P. *Lambertville, N. J.* — The section along the Delaware by Lambertville is spoken of by H. D. Rogers (*c*, 153; *g*, 685) as affording good examples of the metamorphic effect of the trap on the sandstone on both sides of the igneous mass. Cook shows the same region in a generalized section (*a*, sec. 1, here copied, fig. 26), with the traps lying between the sandstones after the manner of sheets elsewhere. The region is one of difficult study, for, in spite of the deep valley cut by the Delaware, outcrops are not continuous enough to show junctions;

it seems hopeless to look for them here, and I was unable to get good evidence as to the position of the trap. It is surely intrusive, as no amygdaloid is present, and the shales are baked on both sides of the trap ridges; but whether interbedded or in dike form, is rather an open question. Against the sheet form may be noted the small difference in slope of the two sides of Sourland Mountain, and consequently the absence of a well-marked face and back so characteristic of the sheets elsewhere; and the fact that the baked and blackened shale ascends to about the same height on either slope (Cook, *b*, 191). Farther southeast, the several elevations known as Rocky Hill, Pennington Mountain, and Bald Pate are on the other hand probably sheets, as their southern face is steeper than the northern: as suggested by Russell, these are presumably the reappearance of the Palisade curve, which is covered by the cretaceous strata in its middle; its length from Haverstraw on the Hudson to Bald Pate on the Delaware would then be over eighty miles.

4. BRIEF STATEMENT OF FORMER VIEWS.

The following paragraphs show in brief the opinions of various writers on this subject, the districts of their observations, and the dates of their publications.

It was thought that the trap was intrusive by Silliman (Conn., 1810, 1830), Hitchcock (Mass., Conn., 1818), Chapin (Conn., 1835), Gesner (Nova Scotia, 1846), Lyell (Va., 1847), Emmons (N. Y., 1846, N. C., 1858), Cook (N. J., 1868), E. S. Dana and Hawes (Conn., 1874), Kerr (N. C., 1875), Prime (Pa., 1875), and Frazer (Pa., 1876). These authors make no special reference to the effect of the eruptions on the position of the sandstone strata in their writings of the above dates. It was held that the intrusion of the trap tilted the sandstones by A. Smith (Conn., 1832), Percival (Conn., 1842), Emmons (1854), and in part by Silliman Jr. (Conn., 1842) and Hitchcock (Mass., 1844).

The following considered the trap intrusive, but held that the dip of the sandstone was due to some other disturbing force: Jackson and Alger (Nova Scotia, 1833), H. D. Rogers, (N. J., 1836), Hitchcock in part (Mass., 1844), Credner (N. J., 1865), J. D. Dana (Conn., 1863–1880), Heinrich (Va., 1878), and Russell (N. J., 1875–1880).

The overflow origin of the trap was faintly suggested by Gibson (Pa., 1820) and Cooper (N. J., 1822); it was shown to be probable by Hitchcock in 1833, and proved later (Mass., 1841–1858); Dawson came to the same conclusion (Nova Scotia, 1848–1868); it was adopted by Lyell in part (Mass., 1842), and fully by Leconte (1878) and Walling (Mass., 1878). These authors agreed with those of the preceding group in believing that the tilting of the sandstones was the effect of some external force.

The trap was considered passively intrusive, and the dip of the sandstone was looked on as the result of original oblique deposition, by H. D. Rogers (Pa., N. J., 1839), W. B. Rogers (Va., 1840), Mather (N. Y., 1843), Silliman Jr. (Conn., 1844), and Whelpley (Conn., 1845).

The former anticlinal connection of the two sandstone strips in North Carolina was suggested by Kerr in 1874, and extended by Bradley in 1876 to the Connecticut and New Jersey areas. Russell independently made the same suggestion for the latter in 1878.

The trap has been considered a metamorphosed sedimentary deposit by Wurtz and Martin (N. J., N. Y., 1870).

Plate I. may be taken as a pictorial supplement, in illustration of the preceding abstracts. It embraces nearly all the sections that have been drawn showing the Triassic traps within their sandstones. These drawings are not fac-similes, but in the small changes that have been made I think no injustice has been done.

1. Hitchcock (*a*). Across the Connecticut Valley in Northern Massachusetts. The vertical position of the greenstone intersecting the strata of Deerfield Mountain was corrected in his next article (*b*), but in the mean time it had served Cooper as an argument for the igneous origin of floetz-trap.

2. Hitchcock (*b*). East Haven (Conn.) dikes; their sides are too regular and parallel. See our figure 44.

3. Eaton (*c*). Across the Connecticut Valley in Northern Massachusetts; excessively wrong.

4. Smith. Across the Connecticut Valley; sandstone tilted by the trap, which rose through chasms and overflowed at the surface.

5. Jackson and Alger (*b*). Southeastern side of Bay of Fundy.

6. Hitchcock (*c*, 221). Across the Connecticut Valley in Northern Massachusetts.

7. Id. (*c*, 423). Turner's Falls on the Connecticut in Northern Massachusetts. The increased thickness of the main trap sheet at the surface is wrong.

8. Chapin (105). Across a number of ridges at Wallingford in Southern Connecticut. The author failed to observe any interbedded sheets.

9, 10. Chapin (109, 111). Details in the same region.

11, 12. Mather (Pl. V., figs. 5 and 4). Dikes in the sandstone under the Palisade trap, two miles south of Haverstraw, and near Verdrietje Hook.

13, 14. Mather (Pl. XLV., figs. 3 and 2). Sections across Southern New York and Northern New Jersey.

15. H. D. Rogers (*e*). Across the Newark Mountains, Central New Jersey. The interbedded position of the trap is not shown.

16. Emmons (*b*, 200; *c*, 107). Palisade section at Slaughter's Landing, showing intrusions between the beds below the main mass of trap.

17. Lyell (*c*, 271). Dike in the Richmond Coal Field.

18. Dawson (*a*, Pl. V.). North shore of Mines Basin, opposite Two Islands, Nova Scotia. Part of this section gives the appearance of a post-Triassic overflow, but it is all described as contemporaneous.

19. Lesley (*a*, 133). Hypothetical section illustrating the use of "overflow" by Rogers as well as by the author.

20. Hitchcock (*g*, Pl. III.) Mount Tom, Mass., with incorrect increase in thickness of the trap sheet as in fig. 7.

21, 22. H. D. Rogers (*g*, II. 912, 691). Dikes at New Hope and Gettysburg, Pa., producing metamorphism and cleavage.

23. Id. (*g*, Geol. Map Pa., sec. 8). General section near Gettysburg, Pa., showing post-Triassic eruptions.

24. Emmons (*d*, sec. 1). Dike in North Carolina.

25. Cook (*b*, 200). True scale section of the Palisades. The author says this "fails to impress the mind" as one of the exaggerated sections does; but it certainly has the advantage of giving a true impression.

26. Cook (*a*, sec. 1). East bank of Delaware by Lambertville, N. J. There is some doubt as to whether these trap masses are sheets as here shown.

27. Frazer (*a*, 298, sec. 11 a). Dikes near Gettysburg, Pa. It is not definitely stated in the context whether faults exist as shown in this section.

28. Leconte (440, 441). Hypothetical section of the Connecticut Valley. If drawn on true scale the amount of erosion would be still more enormous.

29. Russell (*c*, 230). Hypothetical section of the New Jersey and Connecticut Triassic belts, showing their supposed anticlinal relation.

30. Id. (*d*, 47). Section of the Palisade trap at Weehawken, N. J.

31. Id. (*d*, 42). Ideal section of intrusive trap sheet. The descending branches seem to be of improbable occurrence.

5. GENERAL DISCUSSION.

Origin of the Triassic Estuaries. — The small number of Triassic trough-deposits and their absence from the western half of our Eastern mountains go to show that in the making of the Appalachians the synclinals were not, as a rule, absolutely depressed, but on the contrary took part in the general elevation, and rose with the rest of the strata, although to a less height than the anticlinals: as they were continually rising above drainage level, they very seldom or never served as troughs for the accumulation of deposits. But, on the other hand, the estuaries or troughs in which the Triassic strata were deposited must have been absolutely depressed below their previous levels; and it seems reasonable to suppose that the remarkable relation existing between the trap and sandstone areas, so often alluded to, must be mechanically dependent on this downfolding or absolute depression of the estuaries; for here alone where there is evidence of absolute local depression are the only post-carboniferous eruptions of trap to be found from the Green Mountains to Alabama. That this may be truly a relation of cause and effect is made the more probable by the evidence given in the following pages that much of the trap, if not all, was ejected during the downfolding and filling in of the troughs.

Professor Dana (*e*, 113) considers that the subsidence which ended in the post-Triassic eruptions was slow, and not more than five thousand feet, and that it caused in the end only small displacements of strata, wholly inadequate to cause the fusion and ejection of deep-lying rocks from which the traps were derived. He further instances the Green Mountains as a region where the folding was much stronger, and yet where no eruptions but only metamorphism took place, and takes this as arguing against the possibility that the moderate Triassic disturbance was the cause of the fusion and ejection of the traps.

However it may be with the fusion, I must differ from this opinion concerning the eruptions; it seems best, in view of what has been stated above, to suppose that the Triassic disturbance was directly and causally connected with the fact and act of the eruptions. The occurrence of absolute depression in the slightly disturbed Triassic troughs seems reason enough for mechanical eruptions taking place here, although absent elsewhere in regions of greater disturbance but general absolute elevation.

Origin and Deposition of the Triassic Strata. — There seems to be no sufficient reason to look upon these stratified deposits as very abnormal in their origin. Their material was derived from the highlands adjoining either side of their estuaries of lakes of deposit, and whatever the agent of importation — glaciers, streams, waves, or tides — the layers were probably coarser along the shores, finer in mid-water, and all essentially horizontal when deposited. It is noteworthy that those who look on the present dip as the result of original oblique deposition took this ground less from direct evidence in favor of anything so extraordinary, than from the hope of escaping from what seemed a greater difficulty; namely, the tilting to a (supposed) constant dip in one direction in each monoclinal belt.

In addition to the great improbability of the theory of oblique deposition, and its mechanical difficulties of one sort and another, it has to explain why very nearly all the detritus should have been derived from only one side of each estuary; and this in the face of the frequent occurrence of heavy conglomerates of local derivation on the other side. With the coarse material in the conglomerates, there must have been introduced a great quantity of finer detritus, which was carried farther from shore: how could this have been deposited dipping so uniformly towards its origin? The general absence of conglomerates along the outcrop sides of the estuaries, appealed to by Russell (*c*, 231–238, 251) as evidence of open water and not of shore line there, is partly and perhaps sufficiently explained by the fact that the outcrop side must have lost a large share of its original mass on account of its elevation and erosion. But it should be remembered that conglomerates or coarse sandstones of local origin do occur on the outcrop sides of the belts. Such are mentioned by Percival (430), Cook (*b*, 336; *c*, 31, 34), H. D. Rogers (*g*, 669, 677, 679, 760), and Kerr (*b*, 141). An example of pebbles found on one side of a Triassic belt and derived from the other, is given by Wurtz (100): he describes fragments in the sandstone beneath the Palisades coming from Green Pond Mountain, which stands northwest of the Triassic area. Further detailed study on the position and source of these conglomerates is much needed in order finally to prove or disprove the theories above mentioned.

The conditions and order of origin of the various strata, — conglomerate, sandstone, shale, limestone, and coal, — their even, cross-bedded, and ripple-marked structure, and the causes that brought about a change from one to another in this series, cannot be determined with any definiteness until the strata are better co-ordinated than they are at present.

I believe that in Connecticut and elsewhere there are repeated outcrops of the same beds, produced by faults as described below; but their identification is now a difficult matter. Microscopic analysis and detailed study by local observers will do much to solve this difficulty.

Composition of the Trap. — The composition of the eruptive rocks in the Triassic belts is not discussed here, as the present work relates to their physical characters. For this reason, the general term trap is employed throughout. Many names have been previously used, — whin, greenstone, trap, basalt, sienitic basalt, diorite, trachyte, dolerite, and diabase; but the last two would seem the more proper ones, judging by mineralogical composition. Chemical analyses and microscopic examinations of the trap from various localities have been made by Cook, E. S. Dana, Frazer, Hawes, Schweitzer, and Wurtz. The following statement gives the limiting percentages of their results: —

Silica	45.8–53.4%
Alumina	12.5–20.4%
Iron oxides	7.8–21.2%

Magnesia, Lime, Soda, Potash, less than 10% each.

The minerals present are pyroxene, labradorite, and magnetite, with certain accessory species, and chlorite as a common product of alteration. E. S. Dana (391) and Hawes (*a*, 185) note an increase in hydratation and alteration in going eastward across the Connecticut. It is noticeable that the least modified traps are dikes or intruded sheets, and the most modified are overflows, according to the present determinations; thus Hawes describes East and West Rocks and the Jersey City traps as dolerites, and the Saltonstall and Durham Mountains (Conn.) as diabases: Mount Holyoke gives an exception to this apparent rule, as it is classed under the dolerites, although it is certainly an overflow. The two authors above named considered all the trap as intrusive, and consequently did not perceive the natural relationship between conditions of origin and composition, as here suggested.

Relations of the Trap and Sandstone. — Two views as to the origin of the trap sheets have been discussed. According to one, they are considered eruptive across or between the sandstone layers, and more or less active in aiding the breaking, tilting, consolidating, and coloring of the strata, after the period of deposition had ceased. The other view looks on the trap sheets as younger than the sandstones below, and older than those above them; or, as it may be stated, the sandstones and traps are geologically contemporaneous; the sheets are old lava overflows buried under strata of later date than their eruption.

The following review, arranged by localities, beginning in the northeast, will give an idea of the various opinions that have been held.

In 1833, Jackson and Alger (*b*, 276) described the Nova Scotia trap along the Bay of Fundy as "an immense dike, thrown up from beneath the sandstone through some vast and continuous rent, produced by the sudden eruptive upheaving of its strata, which allowed it to spread out laterally only to a very limited extent." In 1846, Gesner included the same traps under the heading "Intrusive Igneous Rocks."

In 1848, Principal Dawson in describing these sheets said (58) that volcanic action "brought to the surface great quantities of melted rock, without disturbing or altering the soft arenaceous beds through which it has been poured, and whose surface it has overflowed." This is quoted in his Acadian Geology, 1868.

Bailey and Matthew mention stratified columnar and vesicular traps and trap conglomerates on Grand Manan; but further speak of the traps as intrusive (219, 220).

For Massachusetts, Hitchcock's first section (1818) shows the trap as a vertical dike breaking across the sandstones; this was soon changed (1823) and the trap and sandstone were described as in alternate beds (*b*, 48), separating the old red sandstone on the west from the coal formation on the east. In 1833, he described the conglomerate on the back of Mounts Tom and Holyoke, consisting of "angular and rounded masses of trap and sandstone, with a cement of the same materials," and concluded that some of the trap must have occurred as a contemporaneous overflow (*d*, 211). In 1844, the same conglomerate is ascribed to small precursory outbursts during the formation of the sandstone; but the larger ridges are considered intrusive and of later date. In 1858, he decides that all the Massachusetts trap is of overflow origin, as will be referred to below.

Lyell was shown the trap conglomerate on the back of Mount Tom by Hitchcock, and inferred "that there were eruptions of trap, accompanied by upheaval and partial denudation, during the deposition of the red sandstone" (*a*, 794). Leconte and Walling both adopt Hitchcock's final view, and it is recently confirmed by Emerson.

The rocks in Connecticut have given rise to other opinions. The elder Silliman held that the trap was eruptive, but did not reach the surface (1810–1830); his observations were mostly made when it was still discussed whether the trap might not be of aqueous origin. Cooper took strong ground in favor of the igneous origin of the trap, but did not concern himself with the manner of its eruption: he implies, however, a belief in overflows (240), though he quotes no decisive observation in this direction. Smith considered the trap eruptive over the tilted layers of the secondary strata (225, 227), and Chapin represented all the ridges about Wallingford as vertical dikes (fig. 8).

Percival states that the traps "have obviously the character of intrusive rocks of igneous origin," which exerted "apparently a controlling influence" in determining the arrangement of the sandstone (10, 11). The trap occurs in dikes and ridges; the dikes are small; the ridges are steep on one side, and on the other are frequently overlaid by sandstone, "thus apparently forming interstratified masses or inclined dikes." "In some instances, where the middle portion of a ridge appears thus interposed, or merely as an overlying mass, its extremities appear as distinct vertical dikes." "The ridge and the dike may thus be regarded only as modifications of the same arrangement." (300.) His use of the term "volcanic" (as 311) does not seem to imply that the eruptive rocks ever reached the surface: nor does "cotemporary formation" (299, 321) seem by the context to indicate the contemporaneous origin of the traps as used in this article. He would apparently agree with those who considered the trap eruptive after the making of the sandstone, often appearing between its layers and strongly affecting its position. The younger Silliman at first (1842) thought the sandstones tilted by the intrusion of the trap, but later reported to the American association of geologists, in 1844, that the sandstone had been deposited as now standing, and that the trap had been intruded without disturbance and had seldom reached the surface. Whelpley held similar opinions.

Professor Dana (*b*, 430) refers to Hitchcock's observations on the back of Mount Tom, and adds, "But after an examination of the region, the author regards it as more probable that the appearance of scoria is owing to an escape of steam laterally from between the opened strata during the ejection of the trap of the adjoining mountain." In the later editions of his Manual, he makes no mention of overflows. He states that the trap "has come up through fissures in the sandstone which varied from a few inches to three hundred feet or more in breadth. In many cases, it has made its way out by opening the layers of sandstone, and in such cases it stands with a bold front, facing in the direction toward which it thus ascended." (*c*, 419; also *d*, 46.) "The manner in which the trap at its eruption has sometimes separated the layers of sandstone, and in this way escaped to the surface, instead of coming up through the fissures simply, shows that the rock had been tilted extensively before the ejection." (*c*, 421.)

Akerly did not decide between the igneous or aqueous origin of the trap of the Palisades (62).

For New Jersey, H. D. Rogers wrote in 1836 that the molten trap had burst up through nearly parallel fissures, after the sandstone had been tilted: the eruption caused no further change in the position of the strata, but produced certain changes in their contents and structure (*a*, 160): and in 1840, "the protrusion of the trap, the formation and deposition of the conglomerate, and the elevation and final drainage of the whole red sandstone basin, have hardly been consecutive phenomena, so nearly simultaneous appear to have been these changes." (*c*, 171.) Cook considers the trap sheets intrusive. (*b*, 176, 200, 337; *c*, 32, 34.) Russell gives good evidence of the intrusive nature of the Palisade sheet (*d*), and claims to have proved the same origin for the First Newark Mountain (*a*). Wurtz regards the Palisade sheet as metamorphosed in place from sediments; he is doubtful if this origin apply to the Newark Mountain as well (101).

Pennsylvania gives so few good opportunities for observation, that little has been written about its trap sheets and dikes, though they are extensive and numerous. Many are omitted from the State Geological Map, 1858. Farther south, dikes seem much commoner than sheets; and so far as I have learned, there have been only two suggestions of contemporaneous overflow for any of the trap southwest of New Jersey. The first, by J. B. Gibson, was written in 1820 and published in 1825: "That the trap may have been deposited on the sandstone by a volcano before the present continent was elevated above the level of the sea, would be a more plausible supposition; but it would be altogether gratuitous." (Observations on the Trap Rocks of the Connewago Hills, 159.) The second was by H. D. Rogers, who wrote: "In certain cases the entire length of each middle secondary belt seems not to have been uplifted to the sea level before the commencement of the trappean eruptions; and those tracts which remained thus submerged are seen to contain, interstratified, as it were, with the later sedimentary deposits, those sandy volcanic tuffs or subaqueous sedimentary forms of trappean matter which constitute the link between the exclusively aqueous and igneous masses." (*g*, II. 762.) The context shows that such cases were regarded as very exceptional in Pennsylvania at least: no definite localities are given. "Overflow," as used by H. D. and W. B. Rogers (*g*, II. 670; *b*, 82) and Lesley (*a*, 133), seems to refer to eruptions after some erosion of the Triassic strata, so that the trap should lie unconformably on the sandstones: they all seem to regard the trap as post-Triassic, with slight exception.

Heinrich accepts the general view of post-Triassic intrusion for the Virginia traps (251). Fontaine writes that the "outpour" of fused rock occurred near the end of the period of deposit (29); but his attention is given more especially to the stratified rocks. Farther south than Virginia, there is no mention of anything but dikes in the sandstone.

It would thus seem that the overflow theory of the origin of the trap sheets has found its most pronounced supporters north of Connecticut.

There is theoretically no difficulty in distinguishing between the intrusive and overflow modes of origin, and the practical difficulty and difference of opinion above shown are probably to be explained by the rarity of good points of observation.

If the traps are intrusive, the sandstone above and below should show about equal signs of metamorphism; there might be fragments of sandstone in the trap, and such should be well baked, but there could be no fragments of trap in the sandstone; the trap might break across the sandstone layers, or send branches off from its main body; the upper surface of the trap should not be scoriaceous, especially in the thin layers, for if intrusive it must have been under almost as much pressure as the lower surface.

Examples of intrusive sheets elsewhere are described by the following authors:—

G. K. Gilbert. Geology of the Henry Mountains (Utah), 1877. The intrusive rock is not vesicular at all; no fragments from it occur in the overlying strata; metamorphism is marked as well above as below the intrusions. The name of *laccolite* was proposed by Gilbert for such masses of eruptive rock, and it may be applied to the Triassic intrusions as well. The laccolites of the West still retain their original horizontal position: those of the East have been tilted since intrusion.

Other less detailed mentions of intruded sheets may be found in the Annual Reports of the Geological Survey of the Territories, 1873, 186 (Marvine), 234 (Peale); 1874, 64 (Holmes), 219 (Endlich); 1875, 60, 95 (Peale), 268 (Holmes); 1876, 194 (Holmes): in the Bulletin of the same Survey, III. 1877, 551–564 (Peale).

A. Geikie. On the Tertiary Volcanic Rocks of the British Isles. Geol. Soc. Journ., XXVII., 1871, 279–310. The flows and intrusions of the island of Eigg are described in detail: the overflows have frequently been regarded as intrusions (292), but the two are easily separated by the difference in their metamorphic effects, and by the presence or absence of slaggy, amygdaloidal structure (281); the intrusions "are almost wholly confined to the lower portion of the volcanic series" (295).

A. Geikie. On the Carboniferous Volcanic Rocks of the Basin of the Firth of Forth. Edinb. Roy. Soc. Trans., XXIX., 1879, 437–518. Both intrusions and overflows are again recognized; in the former, a cellular or amygdaloidal texture is hardly to be observed, and never when they are largely crystalline (475); in the latter, amygdaloids are common (481).

If the trap sheets are old lava-overflows, there must of course be supply dikes, by which the sheets were fed, and these dikes must cut across and bake and be younger than all the strata they pass through, but their cross-section will probably be small compared to the area of the overflows; the sheets will be rather closely conformable to the strata over which they flow, though, as might be expected, their creeping advance while yet molten may have produced some disturbance, and they may contain sandstone fragments; only the previously formed sandstone beneath them can be baked; the upper and lower surface of the flow should differ as in modern lava flows, the upper being more vesicular and uneven than the lower; one flow may cover another; the compact lavas may be preceded or followed by tufaceous or fragmentary deposits; the overlying sandstone must lie conformably on the uneven surface of the lava, adapting itself to all inequalities, and gradually filling them to an even surface; it may often contain volcanic sand or fragments of lava.

Overflow sheets are much more common than intrusions; the following references will lead to descriptions of some of the more notable.

K. C. v. Leonhard. Die Basalt-Gebilde, 1832. This work serves well as a guide to the older European observations on eruptive rocks. Both overflow and intruded sheets are recognized; the former are described as scoriaceous on the surface, while the latter are generally dense, because gas bubbles could not expand in their heavily compressed mass (I. 473); but in speaking of the baking in the adjoining strata (II. 230), the author does not clearly state the different effects of the two kinds of sheets.

J. W. Dawson. On the Lower Carboniferous Rocks, or Gypsiferous Formation of Nova Scotia. Geol. Soc. Journ., I., 1845, (29–31). Several beds of trap conformably interbedded with the adjoining strata; the trap is dense below, amygdaloidal above, and its fragments are found in an overlying conglomerate. (See also *e*, 316, and section, 125; *h*, 49.)

J. S. Newberry. Pacific Railroad Reports, Vol. VI., 1857, ch. vi., vii., the overflows of the Columbia basin. Geological Report of the Colorado River Exploring Expedition, 1861; many observations.

G. P. Scrope. The Geology and Extinct Volcanoes of Central France, 1858, 14.

Medlicott and Blanford. Geology of India, 1879, I. 299. Amygdaloids are very common, especially in the upper part of the various flows.

M. E. Wadsworth. Geology of the Iron and Copper Districts of Lake Superior. Bulletin Museum Comp. Zoöl. Cambridge, VII., 1880, 109–113. The trap sheets are amygdaloidal at the upper surface: they were first shown to be overflows by Foster and Whitney, in 1850, but various opinions have since been expressed concerning them.

In the Western Territories, lava overflows have been very common, and have covered vast extents of country. They are mentioned in nearly all the Western Survey Reports, but their overflow origin is as a rule so evident that few special descriptions are given of the characters that serve our needs of comparison. The following may be referred to from among many others: King, 40th Parallel Survey, I. ch. vii. sec. v. Geol. Survey of the Territories, 1874, 172 (Peale); 1875, 145 (Endlich). C. E. Dutton, Geology of the High Plateaus of Utah, 1880, ch. iii.

The above means of distinction between intrusions and overflows are almost self-evident; but they have seldom been definitely stated in connection with our Triassic traps, and have often been entirely overlooked. The earlier studies of the traps were made when the controversy between the Vulcanists and Neptunists was still unsettled; it was sufficient then to show that the traps were igneous, not aqueous. But later than this, and down even to recent dates, observations on the traps seldom give secure basis for statement of their mode of origin, for the essential and critical points for observation have been very generally neglected. In many cases the older observers gave no special attention to this physical phase of the question; their work being directed to some other of the many difficulties that the Triassic rocks present; and hence from their accounts it is impossible to discover how the trap is related to the adjoining rocks. Even Percival's remarkably painstaking and accurate description of the Connecticut traps is often indeterminate as to their origin; it is greatly to be regretted that he had not better opportunity to publish what he had learned, in addition to simple descriptions.

The rare exposure of contact lines is extremely provoking: in the Connecticut valley alone their combined length must amount to many hundred miles, but so universal is the drift and talus covering, that one seldom finds more than a few feet of "junction" exposed. And this is especially the case for the more important upper contact with the sandstone on the back of the trap; for during the ages in which these rocks have been eroded, they undoubtedly stood frequently or always at a higher level above the sea than at present; the soft beds were deeply worn away, and are now buried under the clays and sands of post-glacial weathering or of glacial deposit. Upper contacts are everywhere rare. Lower contacts are not very uncommon in Massachusetts, Connecticut, and New Jersey; but nearly all contacts are hidden in Pennsylvania and farther south. The discovery and description of the junction of the trap with sandstone above and below it afford excellent field for local observations in all the Triassic belts.

The observations of the past summer, as detailed in the preceding pages, give examples of nearly all the points of evidence required to prove an intrusive or an overflow origin of the trap sheets. The localities where the best evidence of overflow sheets was found are: — Conformable, unbaked sandstone on the trap, or fragments of trap in the overlying sandstone, at Turner's Falls; on the back of Mount Tom and its posterior ridge; and at Feltville, on the back of the First Newark Mountain. Tufa deposit with fragments or bombs of trap, under the second posterior ridge, Turner's Falls. A second lava-flow resting on the uneven amygdaloidal surface of an earlier one, at West Springfield. Percival mentions a trap breccia or conglomerate at several points in Connecticut. Dawson represents a large mass of these fragmental trap deposits in his Nova Scotia section.

Three distinct forms of occurrence must be admitted for these traps: first, the feeders, or supply dikes; second, the intruded sheets, generally lying evenly between the enclosing layers; third, the overflow sheets. The second and third forms are generally closely alike in their present topographic features, and can be distinguished only by detailed observation. Even in the best known districts, there is room for much work of this kind.

Trap Dikes. — Under this heading will be included only those trap masses that have a greater extension across the sandstone layers than parallel to them. They have been observed as follows: —

Dawson and Harrington note a single occurrence of trap on Prince Edward Island in a dike form; it is vesicular and scoriaceous in part, as well as dense and columnar (21).

Bailey and Matthew mention a dike in the Triassic of Grand Manan (221).

Hitchcock says there are no well-characterized dikes in the Massachusetts sandstones (*e*, 655); the only possible case of the kind was found on the south side of Mount Tom, near a saw-mill on a stream, not far from the main road three miles below Northampton (*e*, 656).*

In Connecticut dikes are comparatively common. The first examples recognized were described and figured by Hitchcock in 1823 (*b*, 56); they are in East Haven, eight narrow dikes within four hundred feet. (See figs. 2 and 44.) Chapin was the first to describe and figure some of the numerous and irregular dikes about Wallingford in 1835 (fig. 10). Percival refers to all of these, and adds many others; but it seems that he sometimes applied the word *dike* to sheets, and therefore we cannot say how many of his examples would come within our limitation. Pine and Mill Rocks at New Haven (G) are the largest dikes observed in the State.

Mather gives one or two examples from the face of the Palisades (279, 282, here copied, figs. 11, 12).

Cook finds only two dikes in New Jersey; one near Blackwell's Mills, on the east side of the Delaware and Raritan Canal; the other in a road cut beyond the Flemington copper mine; but he thinks it probable that many others lie hidden below surface drift (*b*, 204; *a*). He later says there are many places where the trap can be seen cutting across the stratified rocks, as by Hook Mountain, Palisade range (*c*, 32).

In Pennsylvania and beyond, dikes become more common. H. D. Rogers figures two examples (here copied, figs. 21, 22), and on the State map (1858) a number are represented within and without the sandstone belt: of the latter, the most remarkable is the long dike discovered by Henderson, which extends some eighteen miles, across the Juniata and Susquehanna near their junction. Frazer describes the dikes in Lancaster and the adjoining counties as so numerous and so difficult to trace that he was unable to represent them all on his map (*c*, 27); he says, also, "The outflow of trap probably followed one or more of the planes of cleavage, of which these rocks are full" (*b*, 325; his sections showing dikes are cautiously drawn without contact lines: compare extract below, under Intruded Sheets).

W. B. Rogers mentions dikes cutting across the sandstones in Virginia (*b*, 82), and Heinrich writes that, "Penetrating the sedimentary rocks, igneous rocks are occasionally met with in the form of dikes" (244, also 250, 263).

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* Since writing the above, Professor C. H. Hitchcock tells me that he has seen one or two small vertical dikes cutting the sandstone in a quarry on the southwest slope of Mount Holyoke about half a mile from the Connecticut, — the only examples of the kind known to him in the State.

Lyell shows a dike in his section of the Richmond coal field (*c*, 271; our figure 17). Olmsted (*c*, 236) and E. Mitchell speak of trap dikes in North Carolina. Emmons does not describe or figure any sheets, but shows several dikes on his sections (*d*; our figure 24). Kerr states that the sandstones are everywhere intersected in various directions by dikes of trap; their thickness varies from a few yards to two or three rods, and their length occasionally reaches several miles: the sandstones and shales are usually blackened for several feet or yards on either side of the dikes (*b*, 146); the dikes are usually transverse to the stratification (*a*, 48).

It would seem from this review that dikes are rare in Nova Scotia, in Massachusetts and Northern Connecticut, and in New Jersey; while they are common in Southern Connecticut, in Pennsylvania, and farther south. They are of all sizes up to two hundred feet, Mill Rock and Pine Rock just north of New Haven being the largest well-known examples. They are, as a rule, dense and compact, with a rough columnar structure at right angles to the sides; some are reported as amygdaloidal, but such are clearly exceptional; their vesicles are very likely not of gas-bubble origin. The sides of the dikes are not smooth, like the sides of most of the dikes in the old jointed slates about Boston, but are more or less irregular or even ragged (fig. 45); implying that there were no joints to guide their fissures. It should be noted, however, that some of the looser sandstone is still almost without joints, and in such cases this point of evidence is of no value. Their metamorphic effects are not far reaching so far as observed: a dike ten feet wide bakes the sandstone for a foot; a hundred-foot dike has some effect ten or twelve feet away. None of these dikes have clearly the form of "necks" or "chimneys," such as are described by A. Geikie about the Firth of Forth (Edinb. Roy. Soc. Trans., XXIX., 1879, 468).

Intruded Trap Sheets. — A number of sheets named in the following list cannot be regarded as fully proven to be of intrusive origin: the evidence for Pennsylvania and the States farther south is very incomplete.

There seem to be no intruded sheets north of Middle Connecticut. Farther south, near New Haven, East and West Rocks (G) and the northern continuation of the latter have long been rightly regarded as intrusions. Smaller examples occur at Wallingford (F), and doubtless many more may be found.

Percival's descriptions make it very probable that all his western line of elevation from East and West Rocks at New Haven north to Southington are intrusive traps. In evidence of this, we may note the general absence of amygdaloid here (mentioned once on 403), and the frequent mention of indurated sandstones above as well as below the trap. The sandstone near the trap by East Rock (W. S. I. 1) * "is remarkably indurated to an unusual width" (395). Two points on the back of East Rock show "highly indurated sandstone" bordering the trap (396). Mill Rock (W. S. I. 2) is a dike rather than a sheet, and is bordered by "light gray very indurated coarse sandstone" (396). West Rock (W. S. I. 4) is overlaid or bordered on the east by indurated sandstone (399). The dikes or ridges of W. S. I. 7 are bordered by "singularly altered and indurated" sandstone (401). Roaring Brook shows indurated sandstone on the back of W. S. II. (403). "At different points, in connection with the western line of trap," dark purple, black, and bright indurated sandstones are found (437). Professor Dana classes East and West Rock, Mount Carmel, and the Meriden Hills with the dikes of Pine and Mill Rock, as trap "that came up melted through wide fissures in the sandstones and subjacent rocks" (*d*, 46).

The Palisades give the largest example of intrusion: this origin was first well proven for them by Russell (*d*; see also our observations, H, J); Emmons noted, a number of years ago, that branching intrusions occurred in the sandstones below (*b*, 200; his figure is here copied, 16). Smaller sheets are found in New Jersey at Martin's Dock (N), and on the Delaware (O); whether the large coarse trap masses by Lambertville (P) are dikes or sheets, I cannot fully decide; but they are not overflows. Cook inclines to the intrusive origin of all of these (*b*, 176, 200); he mentions the occurrence of transverse dikes by Hook Mountain, the north end of the Palisade Range (*c*, 32), which would seem to correspond to the large dikes by West Rock, Conn. H. D. Rogers's sections represent intruded sheets in the Pennsylvania sandstones near the surface (here copied, fig. 23); and Frazer says of the traps about Lancaster County, "As a general rule in this region, their dip corresponds to that of the beds between which they were poured out" (*b*, 318; compare with the quotation above, under Dikes).

W. B. Rogers describes the trap in Virginia as "not unfrequently entering between the layers of sedimentary rock, or pouring out and overspreading them at the top" (*b*, 82); and Lyell writes of the trap in the Richmond coal field that it, "although intrusive, has often here, as is so common elsewhere, made its way between the strata like a conformable deposit." But all these latter references are inconclusive as to intrusions or overflows; they leave the question open for further work.

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* The notation used by Percival.

The trap sheets which are definitely determined to be intrusive show no vesicular structure at any point so far as I have seen them; they are dense throughout, fine at the margins and very coarse in the centre of the larger sheets. Their metamorphic effect on the adjoining sandstones is very marked, as will be described below. The even intrusion of these sheets between shaly or sandy strata is very remarkable. At Martin's Dock and Point Pleasant Station, N. J. (N, O, figs. 51, 52), where this is best shown, trap sheets of various thicknesses, from two to twenty feet, are seen evenly interposed between the strata above and below them for fifty or more feet, without breaking across the layers at any point: in two cases the slaty partings between adjoining trap sheets are less than one foot thick, and yet are continuous for over fifty feet. From this it must be supposed that the molten trap was injected slowly, and that it acted as a liquid wedge, prying open a passage for itself along the planes of easiest breakage that could be found: where two sheets are close together, one was probably intruded after the other. Still it is surprising that any rock could break so evenly as the Triassic strata are thus proved to have broken.

It is not a little interesting to discover that the largest clearly intrusive sheets, the West Rock range and the Palisades, are found on the outcrop side of their respective sandstone belts; they are near what would be the bottom of the sandstone series if the entire formation had received a single monoclinal tilting. The intrusions on the Delaware are also near the base of the formation, as is shown by the appearance of the Matinal limestone not far from them. The probable cause of this is suggested below.

The date of these intrusions is indeterminate. It cannot be fully shown when they took place; whether at about the time of the overflows, that is, the latter half of the Triassic time, or whether their intrusion came later, when deposition was stopped by upheaval and dislocation; but the latter is the more common view.

Professor Dana has already been quoted as taking the position of the trap sheets as evidence that their intrusion came after the sandstones had been tilted extensively (*c*, 421). But the laccolites of the Henry Mountains, Utah, as described by Gilbert, and similar intrusive rocks in Colorado described by Peale (referred to above) lie between horizontal strata; it is therefore not necessary that the sandstones should have been tilted in order that the trap might be forced in between its layers. Professor Dana further argues, from the fact that the trap columns on the face of the ridges are at right angles to the sandstone layers, that "there was a tilting of the strata in progress, before the final breaking and ejections" (*c*, 421). This is also inconclusive; for the same relative position of columns and strata obtains in the sheets that overflowed on horizontal layers, the entire mass being tilted bodily afterwards. We must therefore differ from the conclusion that the eruptions of the trap were necessarily the "closing events of the sandstone period," or that they took place in "a succeeding epoch" (*c*, 421). The overflow sheets were certainly of earlier formation: the intruded sheets may have been so as well.

Russell states that the outbursts of trap occurred after the sedimentary rocks had been consolidated and upheaved, and at the time when the post-Triassic elevation culminated. His evidence for this view is theoretical (*c*, 245, 251) and is seriously weakened by the occurrence of overflows. The generalized section that he gives for the Palisade sheet (*d*, here copied, fig. 31) shows some down-branching dikes of problematic occurrence. Cook classes all the traps as eruptive after the deposition of the sandstones and shales (*c*, 32).

The evidence which points to an early date for the eruption of the intruded sheets is, first, the ragged line of contact with the sandstones where they are broken across; this, as has already been mentioned under the dikes, indicates an eruption before the making of joint planes, and consequently before the tilting; but it is not final or conclusive. Second, the occurrence of intrusions chiefly on the outcrop side of the sandstone belts, or, in other words, near the base of the formation; the only cause that I can suggest for such a limitation of position is that these laccolitic intrusions could only form at a considerable depth, and under considerable pressure, and were therefore placed near the bottom of the sandstones before the latter were tilted: if the intrusions had taken place after the tilting, they might break out at one point as well as another, and would not be likely to have so peculiar a restriction as that above noted. Third, the intruded sheets have the same crescentic form as the overflows; and this, as will be shown farther on, results from folding after the eruptions: while it is possible that the intrusions were guided into their curved line of outcrop by the gently folded strata, it seems more probable that all were folded together.

But, as stated above, this question is at present indeterminate; the above suggestions may serve to counterbalance opinions on the other side of the question, but not to settle the matter. It remains with a number of other points, notably the monoclinal structure, open for further observation.

The force which caused the intrusion of these sheets can hardly have been the expansion of vapors and gases, which plays so important a part in modern volcanoes; for evidence of such expansion (vesicular structure) is wanting. It was therefore more likely mechanical, and connected as already suggested with the downfolding of the troughs rather than with the subsequent elevation and tilting of the sandstones. So far as this holds good, it also points to a Triassic date for the intrusions as well as for the overflows.

Overflow Trap Sheets. — By far the greater number of trap sheets seem to be of overflow origin. The proof of this origin is more or less completely established for the following examples.

The high trap cliffs of the Bay of Fundy are described by Dawson as overflows, but he gives no account of their upper contacts, and his section (here copied, fig. 18) shows much more irregularity than any that I have found in Massachusetts and farther south. But amygdaloids are very common in Nova Scotia, and these seem limited to overflow sheets. On Grand Manan the trap and amygdaloidal beds conform to the adjoining sandstones (Bailey and Matthew, Verrill). The Connecticut valley gives many examples. Farthest north is Deerfield Mountain, as recently described by Emerson and as represented in this paper (A); the long range beginning at Belchertown, Mass., including Mounts Tom (B) and Holyoke, and extending to the Hanging Hills (E) by Meriden, Conn., has been fully shown to be an overflow in its northern part, and it can hardly be of other origin farther south. Its lateral ridges are probably all overflows as well. Hitchcock's observations applied to the posterior ridge on the back of Mount Tom, and should have left no doubt of its mode of formation.

In Connecticut, much observation is still necessary to decide finally on the origin of the numerous ridges. The evidence that favors the intrusive origin of all Percival's western line of elevation has already been stated. Equally good evidence may be found to show that all the large and most of the small sheets of the eastern lines of elevation are overflows. The frequent occurrence of indurated sandstones, and the general absence of amygdaloids, in the west, contrast strongly with the lack of evidence of distinct metamorphism, and the frequent mention of amygdaloids, and trap and amygdaloid conglomerates, in the east. Toket Mountain (E. II.) is described as dense trap at the base, amygdaloidal at the top, and overlaid by friable red shale (Percival, 338). Lamentation Mountain (E. III. 5) has swells of amygdaloid on the back, overlaid by shale (352). The anterior range is separated from the main range of Newgate Mountain (E. IV. **2**. 2) by a band of friable red shale (391). A part of A. 1, S. of E. II. shows a peculiar dark green trap conglomerate, accompanied by beds or dikes of amygdaloid and fine-grained trap (341). A conglomerate east of Saltonstall Lake contains fragments of a fine-grained light green sub-amygdaloidal trap, similar to that in P. 1 of E. I. (324). The ridge anterior to Lamentation Mountain is partly composed of a peculiar trap conglomerate, or rather brecciated amygdaloid, distinctly parallel or stratified in its arrangement (365). Many similar extracts might be noted.

In New Jersey, I believe First Mountain to be proved an overflow by observations at Paterson and Feltville (L and M), although Russell takes the other view. As early as 1822, Cooper wrote that "this mass of floetz trap is poured over the old red sandstone" (240), but it is doubtful whether he had considered the possibility of its intrusion. Second Mountain is probably also an overflow, as its sheet is very amygdaloidal and irregular in structure near the under surface at Little Falls, and its effect on the underlying sandstone is very slight; but its upper contact has not yet been described. Cook mentions pebbles of trap in the sandstone *beneath* the First Mountain (*b*, 337), but later says that no fragments of trap are found in any of the stratified beds (*c*, 34).

There are no decisive observations of contact for the trap sheets of Pennsylvania and the States farther south. H. D. Rogers speaks indefinitely of "overflowed" trap (*g*, 670), of amygdaloid near the borders of certain of the larger dikes (*g*, 671), and of "sandy volcanic tuffs" and "trap shales" interstratified with the sandstones, mostly in Nova Scotia, some in Connecticut and the Middle States (*g*, 762). Lesley's general section (copied in fig. 19) shows "the original sea, the lava and its vent, the manner in which it lifted the new red layers at its outburst, so soon as it was near enough the surface to do so, and overflowed them above" (*a*, 133), but evidence to prove this sequence of events is wanting.

Heinrich mentions that amygdaloids are found in the Virginia traps (244).

The sheets which are proved by their appearance at the contacts to be overflows have the following characters: they produce very little metamorphic effect on the underlying strata; they often show some vesicular structure near the base, sometimes within the mass, and are always very amygdaloidal at the upper surface. It cannot be said that amygdaloids occur only in the overflow sheets, for they are reported in some dikes, and in rare instances in intrusions; but the vesicular structure is as frequent in the overflows as it is rare elsewhere.

Percival noted that the amygdaloids are generally found in the lateral portions of the trap ranges, and occasionally make a large part of the lateral ridges (315); Hitchcock wrote that amygdaloids occupy "the easterly [i. e. posterior or upper] part of the ridges wherever I have examined them" (*e*, 645); and Rogers, that amygdaloids are common "near the borders of certain of the larger dikes" (*g*, 671).

The occurrence and position of the amygdaloid has been variously explained. Jackson and Alger (*b*, 265) thought this texture resulted from the combination of the trap with sandstone and shale. Rogers stated that the amygdaloid occurred "in immediate contact with the altered red shale, by the reaction of the trap upon which this amygdaloidal character has been acquired" (*g*, 761, 763). Cook says that if the cooling of the traps had been "rapid and not under much pressure, they would be more or less cellular" (*b*, 215). Professor Dana considers all the original trap to have been equally anhydrous at its deep source, and to become vesicular by the expansion of steam formed wherever water was met in the process of eruption (*e*, 107). E. S. Dana and Hawes accept this cause.

Several of these explanations are undoubtedly true and possible, but they do not show why the overflows should always be amygdaloidal on the back, and why the intrusions should so generally be compact. It seems most probable that the vesicular texture was produced in these old traps as it is in modern lavas; not so much by meeting water during their eruption, as on account of a decrease of pressure which allowed the occluded gases and vapors to separate from the surface of the overflowing molten mass (Dawson, *d*, 63; *e*, 87). The difference in the composition of the eastern and western traps found by E. S. Dana and Hawes in lower Connecticut has already been referred to as resulting naturally from the better chance the eastern traps have had for alteration.

The area marked by some of the larger ranges is very considerable. The Mount Tom — Hanging Hills range has a front sixty-five miles long, and, judging by the curves at either end, its breadth must be six miles, giving an area of nearly four hundred square miles. If the several loops down as far as Saltonstall Lake all belong to the same sheet, broken by faults, as is suggested below, then the length and breadth would be much increased, and the area might be over seven hundred square miles. The Newark Mountains in New Jersey would in the same way have an area of above three hundred square miles.

But it is not by any means proven that these sheets are the product of single eruptions. The heavy trap which forms Mount Tom (B) decreases in thickness or disappears entirely in going south, and the range is continued for a time by a varying number of smaller sheets. So at Turner's Falls (A), the southward ending of the first and second posterior ridges seems as well explained by the giving out of the trap at the edge of its flow-area, as by the faulting suggested by Emerson. At West Springfield (C), the composite structure of the second posterior trap is well shown. In New Jersey the irregularities in the columnar structure of the Newark Mountains at Paterson and Little Falls (L) may be perhaps explained by supposing each mountain to be the product of several consecutive flows. It seems, therefore, probable that the long trap ranges represent a period of volcanic activity, rather than a single violent outburst, preceded and followed by periods of shorter or less intense activity represented by the anterior and posterior ridges. This is shown in Connecticut far better than anywhere else, and is beautifully illustrated by Percival's remarkable map.

The importance of the overflow trap ranges as marking horizons in the deposit of the sandstones will be referred to later.

*Effect of the Trap on the Sandstone.** — A metamorphic effect is generally attributed to the trap, by which the sandstone in its neighborhood has been indurated and changed in color to a greater or less extent. The most exaggerated form of this idea ascribed the general red color of the whole formation to the effects of trap heat (Hitchcock, *d*, 242; see also Percival, 430, and Dana, *c*, 420); but as red sandstones are common in other regions far from any contemporaneous or subsequent igneous action, it is more probable that their color here as well as there is essentially due to conditions of weathering at the time of deposit. Whether the contemporaneous volcanic action in the Connecticut valley aided the coloring of the sandstones or not, is difficult to say; for bright colored strata are found far from and near to the horizons of the volcanic rocks. But, as a general rule, the baked strata near the trap are not so red as the unaltered layers farther away. Above and below the Palisade trap sheet (H), the rocks were black, gray, or dull reddish-brown, but not strong or bright red as is common elsewhere. Under Mount Tom (B), the sandstones near and at the contact were gray or dull greenish-gray. Along the Delaware (O, P), the layers nearest the trap sheets or masses were black or dark gray; the red strata appeared only several hundred feet on one side or the other, so far as seen: these last are the most extended effects of the trap that I found. In the West Springfield railroad cut (C), the baked sandstone for a quarter or half inch from the contact was almost white on fresh surfaces.

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* I have not yet had time to examine closely the mineralogical changes produced by the trap; some of these, as shown by specimens collected during the past summer, are very striking.

The absence of red color in strata near a contact has been noted by several observers. Silliman described the sandstone close under the trap of Rocky Hill by Hartford as gray or white (*e*, 125). Percival found that the sandstones near the trap were "sometimes discoloured greenish or brown, and at other times their usual reddish color is apparently discharged, leaving them nearly white" (319, also 436): in a few cases they are black or red (437). Lyell found some of the shales turned white below the traps of the Richmond coal field (*c*, 271). H. D. Rogers described the shales near the traps as dull brown or purple (*g*, 673, 678). The change to black color as a consequence of baking is mentioned by Cook (*b*, 206, 212) and Kerr (*b*, 147). In view of these facts, it is impossible to consider the prevailing color of the New Red Sandstone in any way dependent on the action of the trap after the deposit of the sandstones. How much effect the contemporaneous eruptions may have had upon weathering and color, is an open question.

In regard to the effect of the trap on the hardness of the sandstone the most excessive views were those of H. D. Rogers, who considered most of the good building sandstone in New Jersey hardened by baking (*c*, 157); and of Whelpley, who thought that the sandstones had covered a broad area in Connecticut, but had been preserved only near the trap, where it was hardened (62). But here, as before, it may be urged that as hard sandstones occur plentifully in regions free from eruptive rocks, it is more probable that variations in the hardness of the sandy and shaly Triassic strata, except those close to the trap, are due to the unequal action of the ordinary processes of consolidation. Whatever distinct hardening effect was produced by the trap, it generally extended but a short distance into the adjoining rocks, — probably in no case more than one hundred feet. Slight mineral alteration reached farther than any other notable change.

The marked difference between the effects of the intruded and the overflow sheets has already been pointed out. The Palisade trap (H, J) hardened the adjoining sandstones and shales very distinctly for twenty feet and probably farther, and in some of the more easily altered layers produced a marked crystalline structure: this was equally apparent at upper and lower contacts. On the other hand, the lower contact of the overflows shows a very slight change from the normal sandstone. Emerson describes the alteration under the Greenfield trap as extending only an inch from the contact, and the baking as reaching only a foot (196). Under Mount Tom (B), the baking reaches three feet or more. Under the First Mountain trap at Paterson (L), the alteration is distinct for several inches.

The different effects in these contrasted cases evidently depend on the manner and rate of cooling. The intruded sheets must have cooled slower, and entirely by conduction through the enclosing rocks, and hence produced more baking than the others. The difference in the baking effects of different intruded sheets can probably be largely referred to the variations in the composition and the amount of moisture present at the time of intrusion.

Tilting of the Sandstones and Traps. — The remarkable monoclinal structure of several of the Triassic belts has given rise to five suppositions: first, that the present is the original position of deposit; second, that the originally flat layers have been tilted into a monoclinal without faulting; third, that certain paired belts are lateral remnants of a broad, eroded anticlinal; fourth, that the present position is the result of repeated faults and moderate folds; fifth, that a tilting was in progress during the deposition (Cook, *b*, 174; *c*, 34). I am unable to give any evidence for or against this last proposition.

Before speaking of these theories we may note the structure of the several Triassic belts; for some of them do not present any very peculiar features in the position of their strata. On Prince Edward Island the formation shows repeated faint folds (Dawson and Harrington). Around the Bay of Fundy there is an unsymmetrical synclinal, with the greater visible part on the southeast. The Connecticut valley belt has a prevailing dip to the eastward, but with significant exceptions. The long strip from the Hudson extending almost continuously to the Dan River in North Carolina has a similarly prevailing dip to the northwest or west, but also with certain irregularities. The Richmond coal field is a synclinal, strongly faulted (W. B. Rogers and Heinrich). Two patches north and east of it, and the Deep River strip reaching into South Carolina, dip to the east or southeast (Heinrich and Kerr).

First Theory. — H. D. Rogers first thought that some external force was responsible for the tilting (*a*, 160), but soon replaced this supposition with the theory that the several sandstone belts from the Dan River to the Hudson had been deposited with their present oblique dip in a noble river that rose in the mountains of North Carolina and flowed northeast to the ocean about New York Bay; that the occasional reversal of dip was produced by eddies in the great current; and that the monoclinal theory was impossible because the great depth that it required for the sandstone was disproved by the visibility of the old foundation rocks at certain points within the Triassic belts (*b*; *c*, 166–171; *d*; *g*, 671, 761). Mather replaced the river by ocean currents, but otherwise accepted this explanation. Whelpley thought the large and small sandstone areas of Connecticut once connected by a general, oblique deposit, since eroded except where trap intrusions preserved it. This theory has gained few advocates. Oblique deposition on so large a scale and at so uniform a dip as sometimes occurs over large areas is impossible; and as has already been pointed out, the occurrence of plentiful conglomerates on the dip side of the sandstone belts is a strong argument against it. The unsymmetrical form of footprints, as if made on a sloping surface (H. D. Rogers, *d*), is too exceptional to be of much value (Hitchcock, *h*, 17). On the other hand, it need not be claimed that the layers were absolutely horizontal when formed. Some small share of their present dip may be original.

Second Theory. — The theory of anticlinal remnants was first proposed for North Carolina by Kerr, in 1874. It was extended by Bradley (289) to Connecticut and New Jersey, in 1876, and proposed for the same region independently by Russell, in 1878. Heinrich suggests a somewhat similar explanation for the several sandstone patches in Virginia (249), but later considers each estuary isolated (251). The objections to this theory are well set forth by Dana (*g*); it has the serious defect of resting on negative rather than positive evidence; it fails to explain the general absence of trap in the intermediate region, and the occurrence of such an isolated sandstone patch as that of Waterbury, Conn.; the amount of erosion it requires is something enormous; the occurrence of conglomerates along the outcrop side of the sandstone belts has already been mentioned as arguing against it. (See fig. 29.)

The Third Theory supposes the entire body of horizontal strata tilted to a uniform dip, and the upper parts worn off. This has been advocated by Hitchcock (*c*, 221, and later), partly by Cook (*b*, 174), and more recently and decidedly by Leconte (441). Besides the great thickness of strata that this supposition requires, and the enormous erosion it involves, not only of sandstones but of the older rocks on one side, the theory is based on the assumption that there is no faulting or reversal of dip; and this is not proven. If lack of visibility sufficed to prove the absence of faults, it might be said that there are none in Pennsylvania, Virginia, and Tennessee; for fault-planes are hardly ever seen there; they are lines of weakness, and are always covered with detritus. Their existence is known by the repetition of outcrops that they produce, and this test can hardly be applied as yet in the Triassic belts, for the beds there are, as a rule, too little varied to be recognized at their repeated appearances, if such occur. On the other hand, as may be inferred from the position of the intruded sheets, there is evidence that, however numerous the faults may be, they fail to bring up the lowermost strata; and the great sweep of the trap curves in New Jersey would indicate an approach to the simple monoclinal structure. These considerations would imply a great thickness for the sandstone. (See figs. 6 and 28.)

The Fourth Theory looks on the general monoclinal dip as the result of tilting with faulting and some slight folding, but is unable to explain the mechanism of the disturbance; and here with regret I must take my place. Much more observation is necessary before any detailed explanation of this peculiar disturbance can be made. It can now be said only that the disturbing force pretty surely was one of the latest manifestations of the Appalachian mountain-building, which began and had its greatest activity long before; and that the eruption of the trap had no important share in it. Here, as in so many other cases, the trap is relegated to a passive *rôle;* and as already suggested, its eruption was very probably a direct effect of the force which at one time depressed the Triassic troughs, and later deformed the rocks collected in them.

It is sometimes objected that it is mechanically impossible to fault a series of horizontal layers into repeated parallel monoclinals. In answer to this it should be urged that too little is still known of geological mechanism to make such apparent impossibilities of much importance; that faulted monoclinals of gentle dip have been found in the Western plateaus (see Dutton's sections of the High Plateaus of Utah), and of steeper dip in Tennessee (Safford's Geology of Tennessee); and that the Triassic monoclinals show not infrequent irregularity too great to be considered the result of eddies (as Rogers thought), and implying the presence of incipient folds.

As to the occurrence of faults, some of small throw are seen in Delany's Quarry above Holyoke (B), in the West Springfield railroad cut (C), and on the northern slope of Garret Rock, Paterson (L); slickensides are noted about New Haven, in the Jersey City cut, and in Goat Hill by Lambertville. Faults are also shown in the Richmond coal field synclinal by W. B. Rogers and Heinrich, and are suspected by Cook in New Jersey (*c*, 33). Further observation will surely discover others, either directly or by means of repeated outcrops. In this latter way a fault has been determined with a great degree of probability at Beckley, Conn. (D); and a similar one, but of much larger throw, very likely occurs west of Lamentation Mountain, Conn., with uplift on the east, so that the trap sheets seen in Lamentation and in the Hanging Hills are really parts of a single overflow. The evidence of this is the repetition of similar series of strata as described by Percival in the outcrop faces of the two mountains; in each there is sandstone at the base, then the amygdaloid of the anterior ridge, next a limestone at the bottom of a shale, and finally the heavy trap of the ridge line. As shown in fig. 43, the fault is about three thousand feet. It is obvious that a great saving is thus made in the thickness of the sandstone: a moderate depth of formation is made to cover a good breadth of country by its repeated rising to the surface; the layers do double duty, and the vast thickness supposed necessary on the monoclinal theory may be much reduced for Connecticut at least. Similar evidence makes it very probable that the same sheet of trap is repeated by faulting and folding southward from Lamentation Mountain in all the high ridges to that of Saltonstall Lake; but further observation is needed on this point.

We have already stated that the uniformity of dip in direction and amount has been exaggerated, especially by H. D. Rogers, who wrote that in the Connecticut valley there is "only one direction of the dip," and in New Jersey, Pennsylvania, and Virginia, "without exception the strata dip in only one direction" (*g*, 761; also 670). It was thus that he was forced to prefer the theory of original oblique deposition. But this artificial constraint vanishes when we recognize that flat folds with faults are perfectly indicated by the curved outlines of the trap ridges, and by the conformity of the sandstones to these curves; for the trap sheets that are shown to be overflows at once take the important position of distinct horizons in the monotonous sandstones and shales, by which distortion can easily be recognized; just as the scalloped line of outcrop of the Medina sandstone reveals the folded structure of the Appalachians in Pennsylvania.

The conformity of the sandstones to the curved trap ridges is well known, but has never received its proper explanation. Percival described the trap ridges as "arranged according to a peculiar system, conformably with which the secondary rocks are themselves arranged" (10). "The trap ranges . . . . conform, in their arrangement, to that of the sandstone, and indeed have apparently exercised a controlling influence on the arrangement of the latter, thus indicating a cotemporary origin" (321; also 299, 408). He further says that both the general and particular direction of strike of the sandstone strata agrees with the trend of the trap ridges (430–432). Hitchcock noted the same arrangement for Massachusetts (*e*, 654; *h*, 17, and Pl. II.), and Cook mentions it for New Jersey (*c*, 29, 32).

An illustration of a flat fold producing a curve may be seen in the excellent example at Beckley, Conn. (D); it corresponds perfectly with the much larger curves shown by the Turner's Falls — Deerfield Range, by the great range from Belchertown, Mass. to Meriden, Conn., by many other smaller ranges in Connecticut so well shown on Percival's beautiful map, and by several similar curves in New Jersey. The most instructive region for the further study of this important point in the structure of the Triassic belts is without doubt the southeastern corner of the Connecticut sandstone area, about Durham and North Branford, — Percival's "volcanic focus" (311). I had hoped, but was unable, to reach it during the past summer.

All these folds are like flat oval dishes, tilted toward and faulted on the dip side of the general monoclinal; and as a necessary consequence of this, the trap sheets that are folded with the sandstones outcrop in crescentic ridges with the horns of the crescent pointing in the direction of general dip.* The fact of this position was first published by Percival in 1842 (311), but its cause was not then perceived. The folds are very numerous in Connecticut, but in Massachusetts and New Jersey they are fewer and larger: this would indicate that in the last two States there is the nearest approach to the simple monoclinal of the third theory of disturbance. An interesting exception to the rule occurs east of Saltonstall Lake, Conn.; it is P. 2 of E. I. of Percival's notation, and is described as abrupt on its eastern, convex side (325): this makes it seem very much like the eastern edge of a small sheet whose western outcrop is lettered P. 1 on Percival's map. Whether the small curves in southern Durham lettered P. 1 of E. III. are produced by folding, or result from the original form of intrusion or overflow, or are simply the effects of erosion, requires further observation to determine.†

In regard to the crescentic form of the trap ridges, H. D. Rogers considered it natural that the horns of the curves should point with the dip of the sandstone; for as a trap sheet made its way obliquely upward between the layers, the cover of the sandstone must have been cracked at the ends, allowing the trap to rise there and so turn the extremities of its outcrop with the dip of the bedded rocks (*c*). This was agreed to by Silliman, Jr. Whelpley thought the crescent ridges determined by the form of the fissures in the old rocks below the sandstones (64). Dana considered the curved ridges as marking curved fissures, characteristic of certain eruptions, and further added that the agreement in form of these ridges with more prominent features of the earth confirms "the view that ranges of mountains and islands correspond to ranges of fissures" (*a*, 391, 392); but later (*b*, *c*, 21) he essentially follows Rogers's explanation, and further says that the tilting was caused by the subsidence of the estuaries, and is "without evidence of folds" (*c*, 421). Wurtz considers that subsidence went on to a small amount during deposition, and was fastest along the axis of the belt. "Such slight inward inclination of the beds on both sides of the basin, explains the crescent form of the edges of the sheets of trap. The flow or propagation of the metamorphic agent being thus governed." (102.) Russell calls the curves "lines of least resistance," which were naturally and necessarily chosen by the eruptive trap (*c*, 241). Cook says, "The principal changes of dip appear to be, in some unexplained way, connected with the direction of the trap ridges, and are near them" (*c*, 29). All of these explanations, based on the intrusive origin of the trap, fail when the sheets are found to be overflows.

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* The imitation of this crescentic line of outcrop produced at a cross valley is mentioned under the observations at Beckley.

† It is greatly to be regretted that Percival had not the facilities for illustration afforded now by well-executed chromo-lithography. A map of the Connecticut valley drawn with as full an appreciation of topographic form as Percival must have possessed, and colored to show the different varieties of trap and sandstone, is needed to do justice to the remarkable features of this unique region. There is nothing like it known anywhere else in the world.

The value of the overflow sheets as marking horizons in the sandstone formation is thus very considerable, and will in time lead to closer measures of thickness than have yet been possible. The peculiar restriction of the localities of footprints in the Connecticut valley to the strata along the back of overflows is well shown by Hitchcock in the map in his Ichnology: it is evidently connected, as he suggests, with the appearance of volcanic islands and shallow waters in the old estuary.

6. SUMMARY.

The Triassic strata were deposited nearly horizontal in narrow estuaries not greatly exceeding their present area: some degrees of their dip may be the result of original oblique deposition, but this is insufficient to explain all of it. During their accumulation, extensive and repeated eruptions, very possibly from fissures, poured sheets of trap over their surface, to be buried under later deposits; and at the same time, or later, large and small trap sheets were forced laterally between the deep-lying strata. The period of deposition, and probably of eruption, was ended by an uplift that drained the sandstone areas, and tilted the included strata by small amounts from their original position. Some of the strips were bent into simple or faulted synclinals (Nova Scotia, Richmond coal field); one was thrown into gentle waves (Prince Edward Island); the others received their peculiar monoclinal tilting. Why the general monoclinal structure was produced cannot now be clearly explained; but by means of the overflow trap sheets, which serve perfectly as identifiable horizons in the monotonous sandstones and shales, it can be shown that there are distinct folds in these monoclinals, thus explaining the crescentic form of the trap ridges. The folds are of small pattern in Southern Connecticut; on a much larger scale in Nova Scotia, Massachusetts, and New Jersey. Faults also occur: some of small throw are directly visible; some of much greater displacement are properly inferred from the repetition of similar series of strata; and many more probably exist hidden under drift and soil: thus the necessity is avoided of supposing a great thickness for the formation. The erosion of the sedimentary and igneous strata into their present form was probably accomplished in great part during a time of greater land elevation than the present; but it presents nothing abnormal.

The physical features of the Triassic belts that seem most worthy of further observation are, first, a closer identification than has yet been made of the source of the conglomerates that not unfrequently occur along either margin of the belts, thus allowing or excluding the ideas of original oblique bedding and of anticlinal remnants; second, the determination of the overflow or intrusive origin of the many undetermined trap ridges; third, the further proof that the curvature of these ridges implies a folding of the strata; fourth, the closer identification of the surmised but undiscovered faults.

CAMBRIDGE, January 8, 1883.

EXPLANATION OF PLATES.

This article is accompanied by three plates, numbered IX., X., and XI., with fifty-two figures, numbered consecutively.

Plate IX., figs. 1–31, gives a general graphic review of the opinions held concerning the relations of the trap and sandstones from 1818 to 1880. The references to the originals of the drawings are given on pp. 280, 281.

Plates X. and XI. Sketch-maps serving as guides to the localities of the observations above described, and figures representing some of the results obtained. Page numbers refer to explanations in the text.

Fig. 32. Turner's Falls, Mass. Fig. 33. Section of trap ridges (p. 259). Fig. 34. Fragments of trap in overlying sandstone (pp. 260, 300).

Fig. 35. About Mount Tom, Mass. (p. 261). Fig. 36. Section of Mount Tom and posterior ridge (p. 261). Fig. 37. Generalized section of contact, Delany's Quarry (p. 262).

Fig. 38. Railroad cut in posterior trap ridge, West Springfield, Mass. (p. 263).

Fig. 39. Map and section of curved trap ridge at Beckley Station, Middletown Branch Railroad, Conn. (pp. 264, 265, 306).

Fig. 40. The Hanging Hills from Meriden (p. 265). Fig. 41. The same in section (p. 266). Fig. 42. Map of the same (p. 266). Fig. 43. The same with Lamentation Mountain, as seen from Wallingford, Conn., showing place and throw of probable fault (pp. 266, 305).

Fig. 44. Dikes near East Haven, Conn. (pp. 268, 292).

Fig. 45. Side of ragged dike, Wallingford, Conn. (p. 266).

Fig. 46. Base of Palisade trap cutting sandstone, Weehawken, N. J. (p. 270).

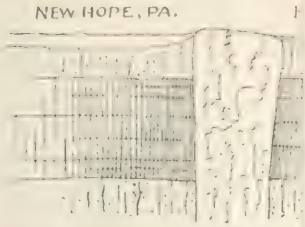
Fig. 47. Garret Rock, First Mountain, Paterson, N. J. (pp. 273,304). Fig. 48. Gorge at Passaic Falls, Paterson (pp. 272, 300).

Fig. 49. Peculiar conglomerate overlying First Mountain trap, Feltville, N. J. (p. 275). Fig. 50. *a*, *b*, the same, natural size (p. 275).

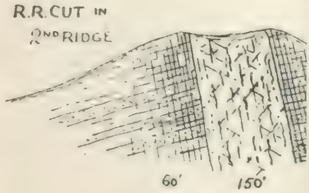
Fig. 51. Intruded trap sheets, Martin's Dock, below New Brunswick, N. J. (pp. 276, 295).

Fig. 52. Intruded trap sheets, near Point Pleasant Station, Belvidere Railroad, N. J. (pp. 277, 295).

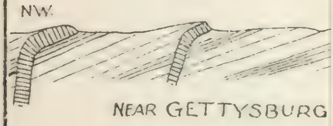
15
N
RS.



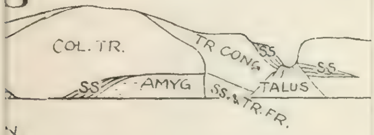
16


R.R. CUT IN
2ND RIDGE
60'
150'

17
'47
E

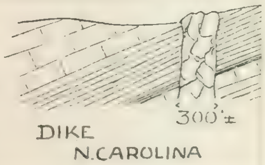

NW.
NEAR GETTYSBURG

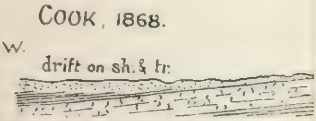
8

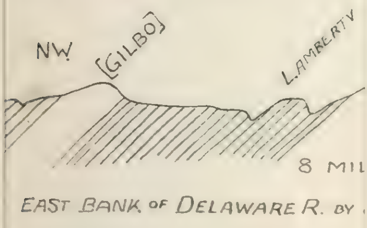

COL. TR.
TR CONG.
SS
SS.
SS
AMYG
TALUS
SS. & TR. FR.

N.

19


300'±
DIKE
N. CAROLINA


COOK, 1868.
W.
drift on sh. & tr.


NW.
[GILBO]
L. AMBERTY
8 MIL
EAST BANK OF DELAWARE R. BY

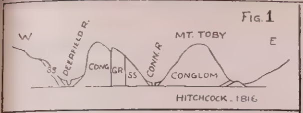
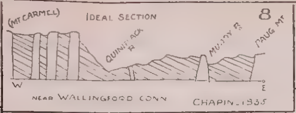
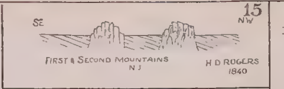
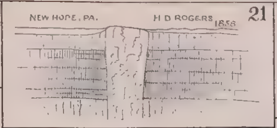
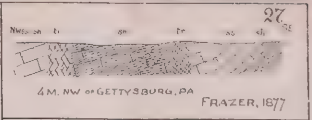


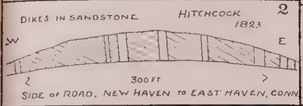
FIG. 1
W
DEERFIELD R.
MT. TOBY
E
SS
CONG
GR
SS
CONN. R
CONGLOM
HITCHCOCK. 1816

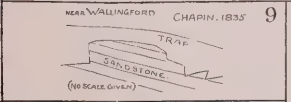

8
(MT CARMEL)
IDEAL SECTION
QUINNIPIAC R
MUDDY R
PAUG MT
W
E
NEAR WALLINGFORD CONN
CHAPIN. 1835

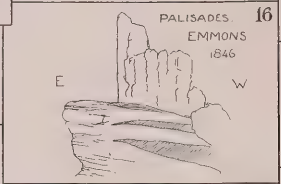

15
SE
NW
FIRST & SECOND MOUNTAINS
NJ
H D ROGERS
1840

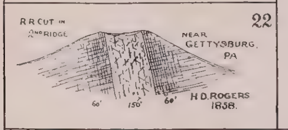

21
NEW HOPE, PA.
H D ROGERS 1858

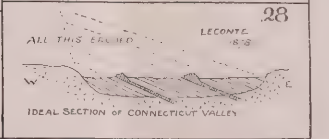

27
NW
sh
tr
sh
tr
ss
sh
SE
4 M. NW of GETTYSBURG, PA
FRAZER, 1877

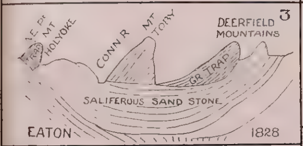

2
DIKES IN SANDSTONE
HITCHCOCK
1823
W
E
300 FT
SIDE of ROAD, NEW HAVEN to EAST HAVEN, CONN

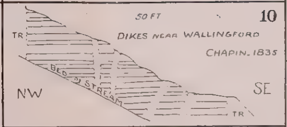

9
NEAR WALLINGFORD
CHAPIN. 1835
TRAP
SANDSTONE
(NO SCALE GIVEN)

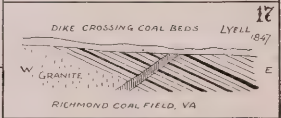

16
PALISADES.
EMMONS
1846
E
W

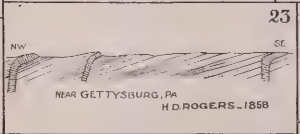

22
R R CUT in
2nd RIDGE
NEAR
GETTYSBURG,
PA
60'
150'
60'
H D.ROGERS
1858.

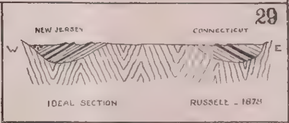

28
ALL THIS ERODED
LECONTE
1878
W
E
IDEAL SECTION of CONNECTICUT VALLEY

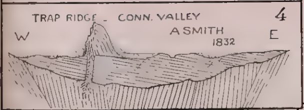

3
TRAP
N.E. PT MT HOLYOKE
CONN R
MT TOBY
DEERFIELD
MOUNTAINS
GR TRAP
SALIFEROUS SAND STONE
EATON
1828

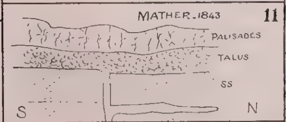

10
50 FT
TR
DIKES NEAR WALLINGFORD
CHAPIN. 1835
BED OF STREAM
NW
SE
TR

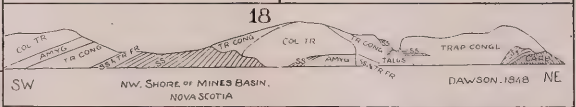

17
DIKE CROSSING COAL BEDS
LYELL
1847
W
E
GRANITE
RICHMOND COAL FIELD, VA

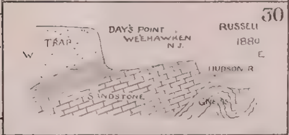

23
NW
SE
NEAR GETTYSBURG, PA
H D.ROGERS. 1858

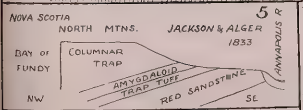

29
NEW JERSEY
CONNECTICUT
W
E
IDEAL SECTION
RUSSELL - 1878

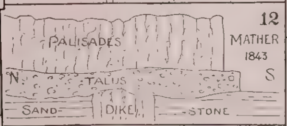

4
TRAP RIDGE - CONN. VALLEY
A SMITH
1832
W
E

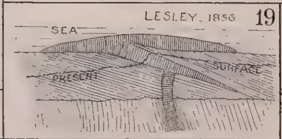

11
MATHER. 1843
PALISADES
TALUS
SS
S
N

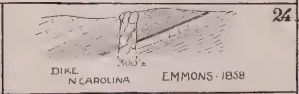

18
COL TR
AMYG
TR CONG
SS & TR FR
SS
TR CONG
COL TR
AMYG
SS & TR FR
TR CONG
SS
TALUS
SS
TRAP CONGL
CARB
SW
NW. SHORE of MINES BASIN,
NOVA SCOTIA
DAWSON. 1848
NE

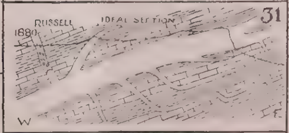

30
TRAP
DAY'S POINT
WEEHAWKEN
N.J.
RUSSELL
1880
W
E
HUDSON R
SANDSTONE
GNEISS

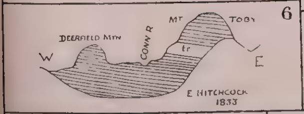

5
NOVA SCOTIA
NORTH MTNS.
JACKSON & ALGER
1833
ANNAPOLIS R
BAY of
FUNDY
COLUMNAR
TRAP
AMYGDALOID
TRAP TUFF
RED SANDSTONE
NW
SE

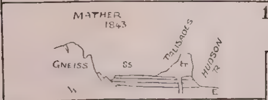

12
PALISADES
MATHER
1843
N
TALUS
S
SAND-
DIKE
STONE

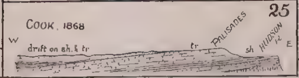

19
SEA
LESLEY. 1856
PRESENT
SURFACE

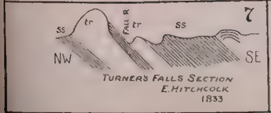

24
300 ±
DIKE
N CAROLINA
EMMONS. 1858

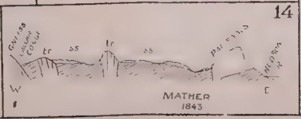

31
RUSSELL
1880
IDEAL SECTION
W
E

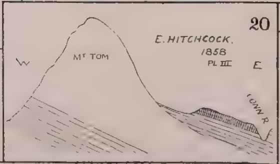

6
DEERFIELD MTN
CONN R
MT
TOBY
W
tr
E
E HITCHCOCK
1833

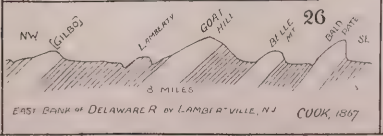

13
MATHER
1843
PALISADES
HUDSON R
GNEISS
SS
tr
W
E


25
COOK. 1868
W
drift on sh. & tr
tr
PALISADES
sh
HUDSON R
E


7
SS
tr
FALL R
tr
SS
NW
SE
TURNER'S FALLS SECTION
E.HITCHCOCK
1833


14
GNEISS
VOLCANIC CONGL
tr
SS
tr
SS
PALISADES
HUDSON R
W
E
MATHER
1843


20
W
MT TOM
E. HITCHCOCK.
1858
PL III
E
CONN R

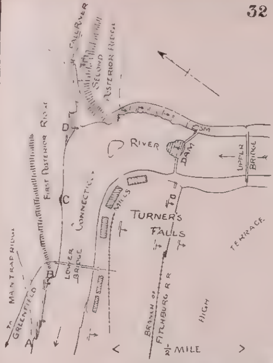

26
NW
(GILBO)
LAMBERTY
GOAT HILL
BELLE MT
BALD PATE
SE
8 MILES
EAST BANK of DELAWARE R by LAMBERTVILLE, NJ
COOK, 1867

PICTORIAL REVIEW
OF THE
SUPPOSED RELATIONS OF THE
TRIASSIC TRAPS AND SANDSTONES
FROM
1818 TO 1880

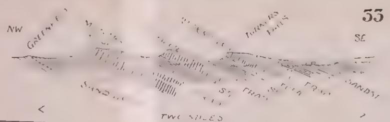
COMPILED BY W. M DAVIS.
1882

The Heliotype Printing Co. 211 Tremont St. Boston

32

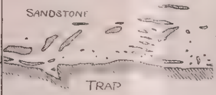

FALL RIVER
SECOND POSTERIOR RIDGE
CONNECTICUT
RIVER
D
C
B
A
CSM
DAM
UPPER BRIDGE
FIRST POSTERIOR RIDGE
MAN TRAP RIDGE
TO GREENFIELD
LOWER BRIDGE
TURNER'S FALLS
TERRACE
HIGH
BRANCH OF FITCHBURG R R
½ MILE

33

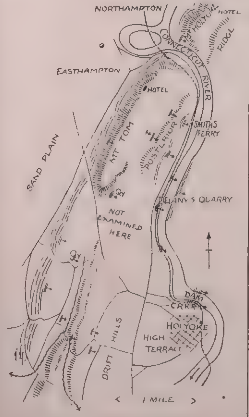

NW
GREENFIELD
TURNERS FALLS
SE
SANDST
TRAP
SANDST
TWO MILES

34

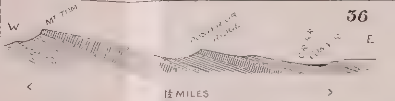
JUNCTION OF TRAP AND SANDSTONE
TURNER'S FALLS.


SANDSTONE
TRAP

35

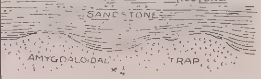

NORTHAMPTON
HOTEL
MT HOLYOKE
RIDGE
CONNECTICUT RIVER
EASTHAMPTON
HOTEL
SMITHS FERRY
SAND PLAIN
MT TOM
POSTERIOR
QY
DELANY'S QUARRY
NOT EXAMINED HERE
QY
DAM
C R R R
HOLYOKE
HIGH TERRACE
HILLS
DRIFT
1 MILE

36

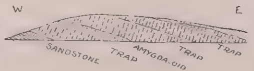

W
MT TOM
POSTERIOR RIDGE
CRAG CONTACT
E
1½ MILES

37

GENERALIZED JUNCTION, DELANY'S QUARRY HOLYOKE

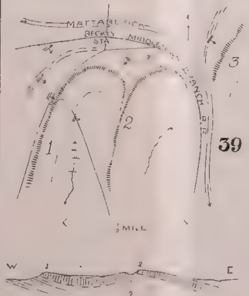

SANDSTONE
AMYGDALOIDAL TRAP

38


W
E
SANDSTONE
TRAP
AMYGDALOID
TRAP
TRAP

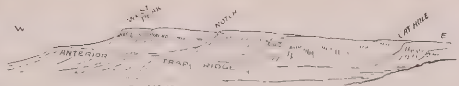
B&A R R CUT, WEST SPRINGFIELD

39


MATTABESICK
BECKLY STA
MIDDLETOWN BRANCH R R
1
2
3
½ MILE
W
1
2
E

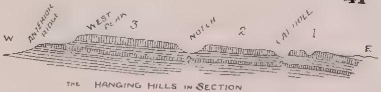
FOLD & FAULT IN TRAP SHEET.
BECKLY, CONN.

40


W
WEST PEAK
NOTCH
CAT HOLE
E
ANTERIOR
TRAP RIDGE

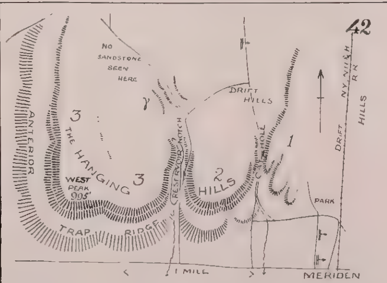
THE HANGING HILLS FROM MERIDEN

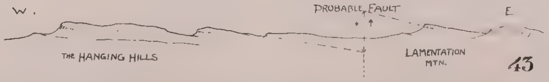
41


W
ANTERIOR RIDGE
WEST PEAK
3
NOTCH
2
CAT HOLE
1
E

THE HANGING HILLS IN SECTION

42

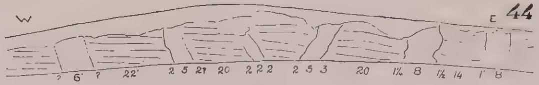

NO SANDSTONE SEEN HERE
DRIFT HILLS
N Y N H & H R R
HILLS
DRIFT
ANTERIOR
3
THE HANGING
3
HILLS
2
1
WEST PEAK 995'
RESERVOIR
NOTCH
CAT HOLE
PARK
TRAP RIDGE
1 MILE
MERIDEN


W.
PROBABLE FAULT
E
THE HANGING HILLS
LAMENTATION MTN.

43

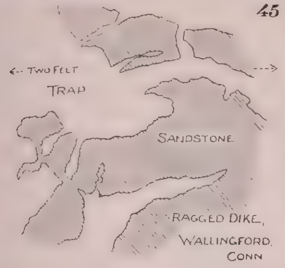
PROFILE SEEN NORTHWARD FROM MT. TOM, WALLINGFORD, CONN

44


W
E
? 6' ? 22' 2 5 2? 20 2 2 2 2 5 3 20 1¼ 8 1½ 14 1' 8

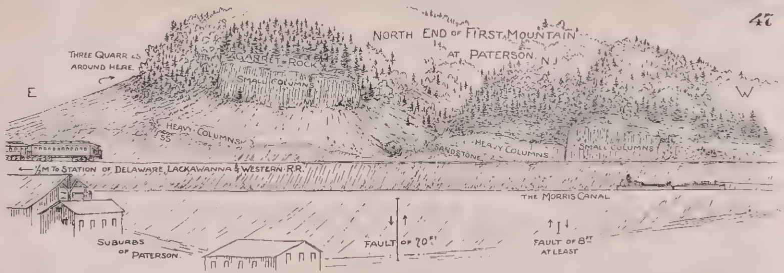
DIKES IN SANDSTONE
ON THE ROAD FROM NEW HAVEN TO EAST HAVEN

45


TWO FEET
TRAP
SANDSTONE

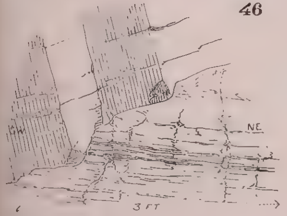
RAGGED DIKE, WALLINGFORD, CONN

47


THREE QUARRIES AROUND HERE
GARRET ROCK
SMALL COLUMNS
E
W
HEAVY COLUMNS
SS
SANDSTONE
HEAVY COLUMNS
SMALL COLUMNS
← ½ M TO STATION OF DELAWARE, LACKAWANNA & WESTERN R.R.
THE MORRIS CANAL
SUBURBS OF PATERSON
FAULT OF 70 FT
FAULT OF 8 FT AT LEAST

NORTH END OF FIRST MOUNTAIN AT PATERSON, N.J

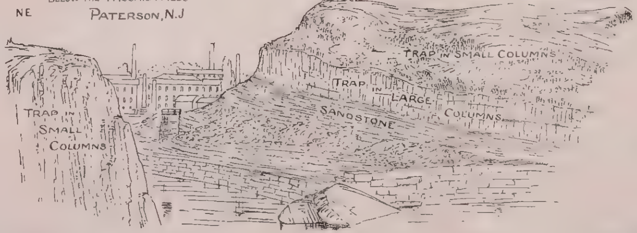
46



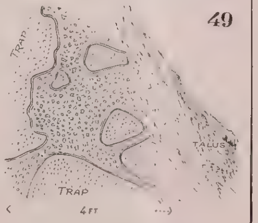
JUNCTION OF TRAP & SANDSTONE NEAR THE DUEL GROUND, WEEHAWKEN, N.J

48 SW

LOOKING DOWN THE GORGE BELOW THE PASSAIC FALLS PATERSON, N.J

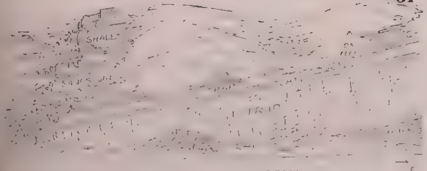

NE
TRAP IN SMALL COLUMNS
TRAP IN LARGE COLUMNS
SANDSTONE
TRAP IN SMALL COLUMNS

49


TRAP
TALUS
TRAP
4 FT

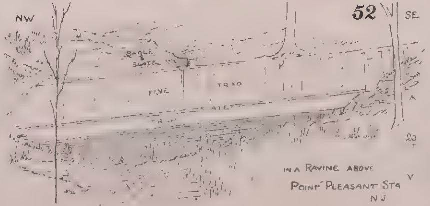
ON THE BACK OF FIRST MOUNTAIN. FELTVILLE, N.J

51


SHALE
SANDSTONE
TRAP
W
E

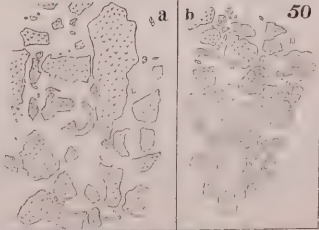
SHORE OF RARITAN RIVER BY MARTINS DOCK 2 MILES BELOW NEW BRUNSWICK, N.J

52


NW
SE
SHALE & SLATE
FINE TRAP
SLATE
A
20 FT
V

IN A RAVINE ABOVE POINT PLEASANT STA N J

50



No. 10. — *The Folded Helderberg Limestones East of the Catskills.*

By William Morris Davis.

Introductory. — Previous Descriptions. — Character and Sequence of the Formations. — *Hudson River Group.* — *Absence of Medina-Niagara Group.* — *Waterlime and Tentaculite.* — *Lower Pentamerus Limestone.* — *Catskill Shaly Limestone.* — *Encrinal and Upper Pentamerus Limestone.* — *Oriskany.* — *Corniferous Grits.* — *Corniferous Limestone.* — *Marcellus Shale.* — *Hamilton and Catskill Sandstones.* — The Question of Unconformity. — Paleogeography. — Folds and Faults. — *The Catskill Gorge below Leeds.* — *Other Points for Observation.* — *Unconformity by Faulting.* — *Compression in Synclinals.* — *Compression in Faulting.* — Surface Geology. — *Glacial Phenomena.* — *Stratified Clays.* — *Former Lines of Drainage.*

The Appalachian district in Pennsylvania is made up of three well-distinguished parts: a plateau of nearly horizontal rocks on the northwest, showing no formation younger than the Carboniferous and Upper Devonian; a rolling low country on the southeast, where the rocks are Lower Silurian and older, greatly folded and often half or wholly crystalline; an intermediate region, where the wave-like folds of the Paleozoic strata are best developed, and their effect in producing anticlinal, synclinal, and canoe mountains is best seen. If we trace these three belts northeastwardly into the Hudson valley, the first is well shown in the broad mass of the Catskills; the second in the perplexing Taconic region from the Hudson across to Western Connecticut and Massachusetts; but the third, so striking in Pennsylvania, has dwindled to a narrow strip of insignificant hills, only a mile or two wide, and a few hundred feet in height. Although so greatly reduced in size, this middle belt still retains its characteristic structure very clearly, and reveals this structure in its surface forms. The accompanying map represents a part of it some ten miles in length, the middle point of which is about west of the town of Catskill on the Hudson. Very little attention has as yet been given to this belt of miniature mountains, excepting in the study of its fossils. The following are the only descriptions referring to it that I have found.

W. W. Mather. Geology of New York; First District. Albany, 1843, pp. 317–352, 366–421. A general description is given of the several formations here occurring, their characters and sequence; but the structural peculiarities of the district are very imperfectly represented.

E. Emmons. Agriculture of New York. Albany, 1846. Vol. I. pp. 134–175, and Plates IV., XX., and XXI., bear more or less directly on the structure of our district.

N. S. Shaler. On the Existence of the Alleghany Division of the Appalachian Range within the Hudson Valley. American Naturalist, XI., 1877, 627, 628. A short notice of the extension of distinct anticlinal and synclinal structure to this point.

W. M. Davis. The Little Mountains* east of the Catskills. Appalachia, III., 1882, 20–33. A detailed elementary account of the structure of a small part of the Helderberg belt; with map and sections.

No geological maps of this region have been drawn on a large enough scale to show anything more than parallel strips of color along the western side of the Hudson valley. The little sketch-map in the last of the above-named articles, and the map accompanying this paper, are the first that show the well-marked Appalachian topography of the district.

The material for the present paper was obtained in part during two short visits in the spring and summer of 1877, the first in company with Mr. E. R. Benton, now Professor of Natural History in the University of Rochester; the second with Professor N. S. Shaler, Mr. J. S. Diller, and members of the Harvard Summer School of Geology. But a third trip made in the spring of the present year furnished fuller results; in this I was accompanied by Mr. J. E. Wolff, Assistant in Geology, and by Messrs. Bunker, Chase, Clark, Dean, and Jackson, students in Harvard College and the Lawrence Scientific School. To all of these I desire to give thanks for aid in making the observations herein recorded.

Our work was mostly stratigraphical, and some description of part of the results has already been published in *Appalachia*, as above mentioned. As only a short time was spent on the ground, the reader must expect to find some points indicated as probable, but not fully established; many of these would afford excellent subjects for detailed summer studies, and I should be greatly pleased to learn of their being taken up by residents or summer visitors.

The Silurian and Lower Devonian strata occurring in this part of the Hudson valley are the Hudson River sandstones and shales in the low country on the east by the river, and in occasional anticlinal valleys within the Little Mountain belt; next, the Lower Helderberg limestones, in good variety and well exposed at many points; over these the grits and limestones of the corniferous period; then the Marcellus shale in a valley, and the Hamilton sandstones in a line of bluffs limiting our district on the west. The latter sandstones or very similar ones continue to the foot of the Catskill Mountains in low ridges and shallow meadow valleys. Whatever paleontological evidence might be discovered by deliberate observation to justify these subdivisions, the lithological character is so distinct that fossils are hardly necessary, except in some of the limestones, for the identification of the several groups. The following table shows the sequence and thickness of the strata as described by several observers here by Catskill and a little farther south near Kingston.

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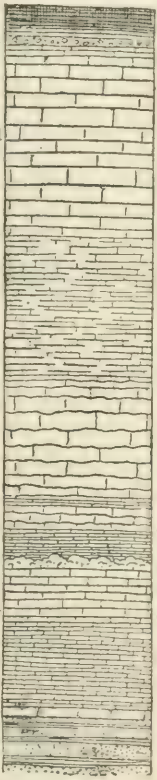
* This name was given by the writer to call attention to the peculiarly mountain-like structure and form of these limestone hills. They are not so known in their own neighborhood.

Grits.		Calcareous gritty shales.	Mather, 1843.	Emmons, 1846.	Lindsey, 1879.*	Dale, 1879.*	Davis, 1882.
Oriskany.		Fragmental.	$\frac{2}{3}$–2	$\frac{1}{4}$			$\frac{1}{2}$
Upper Pentamerus and Encrinal.		Sandy limestone. Heavy and cross-bedded limestone.		25	25 30	20 20	120
Catskill Shaly.		Thin-bedded impure shaly limestone.		60–80	16	15–20	?100
Lower Pentamerus. (Upper Ribbon.)		Knotted limestone.	50		25	20	80
Ribbon.		Fine-bedded.			6–8		
Stromatopora.		Sponge-layer.			8		
Tentaculite.		Fine-bedded.			14		
Waterlime.		Shaly limestone.	100 to 150		40 ?		70
Coralline.		. . . .	. . . .	. . . . . .	6–8	6	?
Hudson River Group.		Shales and fine sandstones.					>1000

* As referred to below, page 321.

The remarkable absence of the Medina-Niagara series of formations between the Hudson River group and the lowest of the overlying limestones will be discussed farther on. Here by Catskill nothing was seen that could be surely referred to any of the missing formations; but Lindsey and Dale describe six or eight feet of Coralline or Encrinal limestone that they identify as some member of the Niagara series. The absence of the Oriskany sandstone is almost as complete.

The formations observed in our sections of the Little Mountains may be described as follows.

The Hudson River group consists of a great series of fine gray or brown sandstones and shales, with no layers here sufficiently marked to be recognized at their probably repeated outcrops. The layers sometimes contain flakes of many-colored clay with the fine sand, implying an erosion near the place of deposition, and some layers have an uneven surface like a mud-flow (see fig. 1). Irregular ripple-marks are common, and in good exposures they may be seen over large surfaces; but we found no cross-bedding or coarse sandy layers. No fossils were seen: their absence cannot be ascribed to metamorphism, either mechanical or chemical, for many of the strata seem very little altered in spite of the general disturbance. These rocks are well exposed at many points where they crop out above their usual terrace covering of clays and sands that are spread over all the low land; and are also shown on the creek sections, as on the bank of the Catskill at Catskill Village, where excessive and irregular plications may be seen (fig. 2); sharp folds, slickensides, and small faults are very common; and likely enough faults of larger throw occur, though they cannot be detected. A point of good continuous, and just now of fresh exposure, is in the railroad cut on the bank of the Catskill just below Austin's Mill; a fine dome-like fold is seen by the stream, and farther on broadly curved surfaces of rippled shales alternating with firm sandstones dip conformably under the limestones (fig. 3). Unconformity might well be expected: the Medina, Clinton, Niagara, and Salina series, about one thousand feet thick in Western New York and over six thousand in Central Pennsylvania, are all absent here, unless some few feet of nondescript beds may represent them.* The evidence of conformity and the possible meanings of this absence of formations are discussed farther on.

The beds of passage from Hudson River to Lower Helderberg were best seen on the road leading down to Austin's Mill (fig. 3), and at the north end of the Quarry Hill: they are sandy limestones, without fossils as far as observed, and not more than five or ten feet thick between characteristic Hudson River sandstones and shaly layers of the Waterlime.

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* If the shaly layers of the Waterlime are considered equivalent to the Salina, this must be a little modified.

There is no distinction attempted on our map and sections between the Waterlime and the Tentaculite limestone: all the calcareous layers below the knotted strata of the Lower Pentamerus are marked by a single color. Professor Hall (Paleontology of New York, III. 386) describes the Waterlime as being of "gray or drab-colored surface and darker interior color, and almost destitute of fossils"; while the Tentaculite is "a thinly bedded blue or black limestone, abounding in certain organic remains." These characters are easily recognized. The total thickness of seventy feet was measured on the eastern slope of the Quarry Hill, from the uppermost sandstone to the lowest knotted limestone. At Austin's Mills the measure would be less. The subdivisions of the Tentaculite, as described at Rondout (see Lindsey and Dale, as below), are here clearly made out. Some ten feet of fossiliferous limestone are followed by the Stromatopora layer, of one or two feet thick, with numerous sponges a foot or a foot and a half in diameter (fig. 4); next above come twelve feet of fine Ribbon limestone, in even parallel layers, shown by alternating bands of lighter and darker color, often as thin as one twentieth of an inch; then comes the coarse Lower Pentamerus, but about ten feet above its base there is a band of Ribbon limestone again, one or two feet thick. The even lines and smooth gray weathered surface of the Ribbon limestone frequently serves as a well-determined horizon, outcropping on the slope of the ridges made by the Lower Pentamerus.

The fossils of the Tentaculite limestone commonly seen are a *Leperditia*, a *Tentaculite*, *Orthis plicata*, and a *Turritella* (?). The first two are very common on certain layers. The thickness of the Waterlime and Tentaculite has already been mentioned as seventy feet or less. These two divisions of the limestone group are well seen — at least their upper members — at many points along the front of the Kalk Berg, around the synclinal outlier opposite Austin's Mill, and at the head of the southern anticlinal valley.

The change to the coarse, heavy, knotted layers of the Lower Pentamerus is accomplished within two or three feet. With this comes the frequent occurrence of dark chert in irregular masses up to six inches in diameter. The fossils easily found are *Pentamerus galeatus* (beaks are very common on weathered slopes in the soil) and *Atrypa reticularis*: both are common. The thickness measured about eighty feet on the eastern slope of the Quarry Hill. The best exposure is on the Catskill on the first bend above Austin's Mill, where broad surfaces of the limestone are laid bare; it is fairly shown in the ridges or bluffs all along its outcrop.

The Catskill (formerly Delthyris) shaly limestone is a rather evenly bedded, thin splitting, impure dull blue rock weathering gray or brown as its calcareous particles disappear. Fossils are very common, but on weathered outcrops are found only as casts: the ordinary forms are *Spirifer macropleura*, *Spiriferina perlamellosa*, *Streptorhynchus* (*Hemipronites*) *radiatus*, *Strophomena rhomboidalis*, *Rhynchonella ventricosa*, *Eatonia peculiaris*, and *Pterinea communis*.* The thickness of this division is somewhat under one hundred feet. The best exposure is at the railroad bridge across the Catskill, three quarters of a mile below Leeds, and on the banks farther down stream; but characteristic fossils are easily found at many points.

The Encrinal and Upper Pentamerus limestones were not separated in our study, as they constituted a single topographic element; but it was readily seen that crinoid stems were more plentiful in the lower than in the upper layers. The rock is hard, heavy-bedded, and coarse-grained, consisting of broken shells and crinoid stems; it is well adapted to heavy masonry; on some weathered joints, exposed in French's Quarry, very clear cross-bedding was seen. Corals make no important share of these limestones so far as we could discover. The shells recognized were *Pentamerus pseudo-galeatus*, *Spirifer cycloptera*, and many others not determined: they are so firmly held, that it is difficult to break out good specimens. The thickness of these two members as determined at the railroad bridge below Leeds is one hundred and twenty feet, but this may be exaggerated by local faulting. Other observers give it much less. French's Quarry and the Catskill bank by the railroad bridge give good exposures; and fair outcrops are found at many other points.

These Lower Helderberg limestones as a whole are decidedly harder than the shaly sandstones below or the grits above them, and are strongly determinant in forming ridges and bluffs. Among the most marked of these is the long, continuous ridge at their easternmost outcrop, known as the Kalk Berg (corrupted into Kalla Barrack †), where they are usually nearly vertical and sometimes are overthrown: other interesting forms of outcrop appear on the several synclinal and anticlinal folds.

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* The names are thus given in the collection in the American Museum of Natural History, New York.

† For these local names I am indebted to Mr. Henry Brace of Catskill.

The subordinate ridge-making members of the group are well shown in the Quarry Hill synclinal; they are the Lower Pentamerus, the upper part of the Catskill Shaly, and the Upper Pentamerus; while the Waterlime, the junction of the Lower Pentamerus and Catskill Shaly, and of the latter with the Encrinal, are marked by depressions. These relations of hardness are pretty constantly shown in all parts of our field, and add much to the ease of identification of the several subdivisions.

The upper part of the Upper Pentamerus becomes sandy and impure for about ten feet: this change is completed in the occurrence of a six-inch layer containing limestone pebbles up to an inch in diameter, and quartz grains of a quarter of an inch or less. Although no fossils were found in this thin conglomerate, I have considered it as representing the Oriskany sandstone, as it has the proper place in the series. Mather and Emmons describe it as half a foot to two feet thick. The best exposure of this layer was found on the north bank of the Catskill at Leeds, in the vertical strata on the western side of the anticlinal that shows there in the stream; and again at several points below, as far down as the railroad bridge.

The Grits which come next are fine-grained, dark gray or bluish, and generally with all appearance of bedding destroyed and supplanted by an imperfect, nearly vertical cleavage. Bedding planes are sometimes found, and generally contain impressions of the *Spirophyton cauda-galli*. Very few other fossils were found in this monotonous formation. Its thickness is three hundred and fifty feet, when measured by the breadth of outcrop where the enclosing limestones were about vertical, east of the limekiln near the junction of Old Kings and the Mountain roads. Other observers give only a fifth of this thickness. Outcrops are generally poor, as the rock usually weathers down to a rolling surface of gray gravelly soil, or is covered by swamps; the lower half of the Grits is more easily eroded than the upper: the gorge of the Catskill by Leeds presents on its southern bank an excellent section of the entire formation (fig. 5), and exhibits perfectly the relation between its true bedding and secondary fracturing. A small table-rock, over which a little stream falls on its way to the Kaaterskill west of West Berg, an eighth of a mile north of the limekiln above mentioned, shows many slabs near the top of this formation well marked with the cocktail seaweed.

The Corniferous limestone follows the Grits by an abrupt change; its layers are often massive, and always of a fine, close grain. Dark hornstone is very common in irregular masses often a foot broad; it is clearly of secondary origin. Fossils are scarce; the corals so common farther west are hardly seen here, but the fine, massive limestone was very possibly largely derived from a coral reef not far distant. There was no good place to estimate its thickness; but twenty-five or thirty feet, as given by Emmons, seems too small. The margins of this formation have a peculiar way of weathering out into large loose blocks, often ten feet cube; good examples are seen on Old Kings road just south of the Mountain road; near Van Luven's Lake; and north of Hooge Berg. The last-named point gives a good section of the limestone at its southern end, and it can be well seen at Leeds west of the Grits.

The Marcellus shale follows by a very abrupt transition, as may be seen at its only exposure, on the east bank of the Cauterskill, just south of the Mountain road bridge. It is a fine black fissile shale, in which a few faint fossil shells were found in 1877. Its upper limit and thickness were not determined, as it is throughout worn down into a valley between the Corniferous on the east and the Hamilton on the west, and deeply buried under stratified clays. The Hamilton sandstones and shales and the overlying formations were not examined closely; the lower layers of the former are well shown at the Big Falls of the Kaaterskill, where several strata are very fossiliferous; *Spirifer mucronata* and *medialis* are both of common occurrence. From the Marcellus valley to the foot of the mountains these and similar, but non-fossiliferous, sandstones and shales continue with a gentle westerly dip, and their thickness must amount to over two thousand feet. From the foot of the mountains to the summits of their broad masses, the strata are essentially horizontal, and may measure about three thousand feet more, chiefly of sandstones and sandy shales, with some conglomerates near the top. These are generally accounted of the Catskill formation. Cross-bedding is common throughout, and in a great part of the Hamilton group.

The most interesting question presented by this series of rocks turns on the absence of the Medina, Niagara, and Salina strata from between the Hudson River and the Lower Helderberg formations, and the possibility of unconformity at this point of the section. The following historic review will show what observations have been made and what views have been held on this subject in the Hudson valley.

W. W. Mather. Report of W. W. Mather, Geologist of the 1st Geological District of the State of New York. Albany, 1838. (2d Annual Report.) "Mount Bob and Becraft's Mountain are outliers of limestones, lying unconformably upon the subjacent slate rocks. I have traced these rocks within a few feet of their junction in many places." (p. 165.)

The same. Fourth Annual Report, 1840. The Hudson River slate group "is overlaid unconformably in many places by the various rock formations of more recent origin." (p. 212.) The common and hydraulic limestones at the base of the Helderberg series "sometimes rest unconformably upon the Hudson slate group, as at Lawrence's quarry, on the Rondout, opposite Wilbur (see fig. 6, copied from fig. 1, Pl. 26, Final Report, 1843); sometimes conformably on the Shawangunk grit, ... as at Rosendale and Lawrenceville, on the Rondout; sometimes on the red and variegated shales and grits that overlie the Shawangunk grits, as at the High Falls of the Rondout in Marbletown." (p. 237.) Lawrence's quarry is again mentioned (242) as affording "a fine exposure of the different strata, and the Hudson slates are seen *unconformable*, below the limestones." At Hasbrouck's quarries on Pine Mountain between Rondout and Kingston Point, the Hudson slate series dips 40–60° to E. S. E.; the overlying limestone and cement beds dip 80° W. N. W., "and this dip continues nearly uniform along this line of upheave to the 'High Rocks' above Kingston Point." (p. 242.)

The same. Fifth Annual Report, 1841. There is "a line of fracture and anticlinal axis" extending northward from New Jersey, passing Kingston and the district here mapped. "On the west side of this axis of fracture and elevation, the rocks dip to the westward at variable, but generally at small angles, while on the east side they dip at a high angle to the eastward, and are frequently vertical in their stratification." (p. 64.) Further reference to Becraft's Mountain is made on page 90; it is also said that west of the line of fracture "the superincumbent rocks overlie this [Hudson slate] series conformably in most places." The several Helderberg outliers known to Mather are Becraft's Mountain and Mount Bob near Hudson; another in Greenbush, between the Sandlake and Nassau roads, about two miles from Albany, first examined by Dr. Eights; and two others described by Eaton, one in the north part of Greenbush, five miles southeast of Troy, the other in the town of Schaghticoke, on the north side of Tombannock Creek (p. 87).

The same. Geology of New York, First Distrct, 1843. Most of the observations are repeated from the Annual Reports, pp. 330–373. Becraft's Mountain is described in detail (p. 351) and figured (Pl. 24, fig. 6, here copied, fig. 7); no doubt is expressed of the unconformity there; but at Mount Bob (Pl. 38, fig. 1, here copied, fig. 8) it is said to be "apparent." "Although the actual junction of the rocks of the Hudson River group with those of the Helderberg division was not observed between Kingston and Catskill, they were seen in many places so *nearly* in contact, and unconformable, as to leave scarcely a doubt that they were really unconformable" (p. 374); and they are so shown in his section on Esopus Creek (Pl. 7, fig. 9, here fig. 9); the author suggests that the Hudson series may have been disturbed first only to the east of the "anticlinal axis," and, later, to the west with the overlying formations (p. 374). But his section (Pl. 38, fig. 14, here fig. 10) at Catskill shows conformity.

H. D. Rogers. Second Annual Report on the Geological Exploration of the State of Pennsylvania. Harrisburg, 1838. The sandstone and conglomerate of IV. (Oneida and Medina) are "displayed near Rondout, resting *unconformably* and with a gentle inclination upon the steeply uptilted, contorted, and disrupted strata of the immediately subjacent slates" (p. 37). In Pennsylvania, the conglomerate at the base of IV. contains fragments of the three earlier formations, showing a violent physical change; but no unconformity was noted there (p. 36).

The same. On the Correlation of the North American and British Palæozoic Strata. Brit. Assoc. Rep., 1856 (178–180). "Undulated Matinal rocks support horizontal Niagara or Scalent strata, with a lapse of two intermediate formations for some distance from the Hudson, westward along the base of the Helderberg range." (p. 178.) In the Mohawk valley, these formations approach conformity. Southwestward to Alabama there is neither lapse of formations nor unconformity, but a violent change in the rocks in passing from Hudson River to Medina strata; the latter contain fragments of earlier formed layers.

The same. Geology of Pennsylvania, 1858, II. (784–787). "From Gaspé on the Gulf of St. Lawrence, S. W. to the River Hudson, wherever the Matinal rocks appear in contact with any of the superposed formations, the former are either highly inclined and folded, or give evidence of disturbance and partial metamorphism, while the overlying strata display much less displacement and alteration." (p. 785.) Becraft's Mountain and Rondout (fig. 11, here copied from Vol. II. p. 785) are mentioned as points where the unconformity is distinct. It is said to exist "from Rondout to Schoharie" (p. 785).

E. Emmons. Agriculture of New York. Albany, 1846, I. The sections in the gorge of the Catskill at Austin's Mill and at Becraft's Mountain are drawn showing a conformable sequence of Waterlime on Hudson River layers (his sections 5, Pl. XX. and p. 136, here figs. 12, 13); at Rondout, the relation is represented as unconformable by faulting (fig. 17, p. 134, here fig. 14).

James Hall. Palæontology of New York, Vol. II. Albany, 1852.

"Along the base of the Helderberg, where the Clinton, Niagara, and Onondaga salt groups are very thin, the Oneida conglomerate is absent, and the shales and sandstones of the Hudson River group rise to within a few feet of the Tentaculite limestone or Waterlime group." (p. 1, note.)

The same. Palæontology of New York, Vol. III. 1859. The author repeats a doubt previously expressed as to the truth of the unconformity at Becraft's Mountain, and states that the Upper and Lower Silurians are conformable on the northern front of the Helderberg Mountains (p. 33, note). Farther on, he writes: "The Hudson River group, which constitutes a few feet of their [Catskill Mountains] elevation at the base, is disturbed, and the succeeding beds lie upon this unconformably" (p. 69); and again, "the unconformability of the Lower Helderberg group upon the Hudson River group" shows that the subsidence of the old sea bottom was periodical (p. 70; see also p. 88).

These are the older observations on the subject. The following references show the recent work, as well as the lack of agreement on the question in the two text-books in more general use.

J. Leconte. Elements of Geology. New York, 1878. "In the United States, the rocks of the whole [Paleozoic] system are conformable." (p. 277.)

J. D. Dana. Manual of Geology. New York, 1880. The making of the Green Mountains came at the end of the Lower Silurian (211, 212); the disturbance extended to the Hudson (214). Localities of unconformity mentioned are near Gaspé, near Montreal, and at Becraft's Mountain (216,* 241). The disturbance is thought not to extend southwestward of New Jersey (217).

J. G. Lindsey. A Study of the Rocks. Poughkeepsie Soc. Nat. Sci. Proc., II., 1879, 44–48, giving a careful description of the rocks at the Rondout cement quarries, and regarding the junction of the Upper and Lower Silurian rocks as unconformable.

T. N. Dale. The Fault at Rondout. Amer. Journ. Sci., XVIII., 1879, 293–295, from which figure 15 is here copied, showing the Lower Helderbergs, with a thin layer of Niagara (Encrinal) limestone at the bottom, lying squarely across the tilted Hudson River strata.

It would seem from this review that Mather and Rogers regarded the contact of the Upper and Lower Silurians as unconformable on both sides of the Hudson; Emmons figures a conformable relation, and considers the apparent unconformity at Rondout the result of a fault; Hall at first admitted the general unconformity, but later doubts it even for

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* Here Becraft's Mountain is wrongly said to be west of the Hudson.

Becraft's Mountain (but not for Rondout?). Leconte, on I know not what authority, takes a view opposite from the generally accepted one given by Dana. Lindsey and Dale both represent the junction at Rondout as an unconformity.

West of Catskill, I am persuaded that no unconformity exists: the evidence for this conclusion is given below. Becraft's Mountain and its smaller neighbor I have not seen, except from the railroad in passing: the opinions concerning this important point are contradictory, Mather and Rogers being opposed to Emmons and Hall. About Rondout no disagreement is directly expressed except by Emmons; and yet none of the observations or figures of the hill-sections in that district are conclusive; none enable the reader completely to exclude the possibility of the apparent unconformity being really a junction by faulting. It would seem, therefore, that all this subject needs reviewing.

The observations on which I rely to prove the conformable sequence of the strata in the district here mapped are as follows: —

First. At the north end of French's Quarry Hill, by a good spring on the middle one of the three roads that run around the slope, there is a contact of sandstone and an impure limestone clearly shown for some ten feet. The rocks here lie horizontal in the axis of a synclinal fold; their strata are closely parallel, and evenly superimposed; going down hill several outcrops of sandstone may be found; ascending to the south, the several limestones of the Lower Helderberg group are easily recognized in proper order; going east or west, the Hudson River strata soon rise from the synclinal axis, becoming steeper and steeper by gradual change.

Second. In the road and railroad cuts just east of Austin's Mill on the Catskill, the absolute contact is hidden by about ten feet of detritus, but the strata show only parallel arcs of the eastern half of a synclinal (see fig. 3). The apparent unconformity in the limestones here shown is due to horizontal faulting in the trough of the fold, as is described farther on.

Third. Along the front bluff of the Kalk Berg, generally marked by vertical strata of Waterlime and Lower Pentamerus, the sandstones are also vertical and parallel in strike; in the anticlinal valleys within the belt, the sandstone is perfectly conformable to the curves of the limestones, but no absolute contacts were found.

We therefore must conclude that the entire series is conformable in this district, and is folded together; and so it is represented on our sections.

When the attempt is made to restore the geographic changes by which the several strata were made to vary, it cannot be denied that this conformity is difficult to understand. The sands of the Hudson River group indicate a return of the shore line on the east after the open ocean conditions of the Trenton formation;* the shallowing of the waters and the westward advance of the shore continued certainly as far as the present line of the Hudson. If the unconformity at Becraft's Mountain be accepted, then we may follow the generally allowed belief in the folding of these sandstones accompanied by their elevation and erosion; and the very variable composition of the Niagara group as a whole, and the probable changes of level during the Onondaga (Salina) period are most likely to be explained by the oscillations of the adjoining land on the east during the Green Mountain growth. Excepting the few feet of beds found at the northern end of the Quarry Hill, which were not definitely referred to any group, there is nothing to be seen in the Catskill section to represent this vast lapse of time; for directly and conformably above the Hudson River sandstones come the Lower Helderberg limestones, which mark the second and greater eastward advance of the sea in the Upper Silurian, the first being that of the Niagara limestones. The present Catskill district cannot then have been dry land, for it shows no eroded surface beneath the Lower Helderbergs so far as we could discover. It could hardly have been far under water, for then it should have received some share of the various sediments so plentifully supplied to the ocean farther west and southwest. It may, therefore, be best to suppose that our district lay just off shore, or almost between wind and water, and either received very little detritus, or else was alternately covered and swept bare again by shoal water currents, so that in the end it had gained scarcely any rock material.

The change that followed next was not so much a depression of the ocean floor as a distant eastward retreat of the shore line; for the Lower Helderberg limestones show shallow waters, with freedom from shore sediments such as the Green Mountain rocks could have furnished. The Catskill shaly limestone probably marks a slight departure from this open ocean, and the presence of a neighboring shore, for it contains much more non-calcareous material than the limestones above and below it.

This second oceanic cycle ends with the Oriskany sandstone, marking a return of the shore, though perhaps not a very near approach; and a third cycle culminates in the Corniferous limestone, with deeper water here than the second. The Marcellus shale, which follows abruptly, seems too fine-grained and even-bedded over large areas to mark either a change to shallow water or a neighboring shore; the disappearance of the limestone below it was more probably connected with a further deepening of the water, or with a change in its temperature. But shallow water and near shore conditions came very clearly in the cross-bedded Hamilton and higher sandstones, and even more distinctly in the Catskill conglomerates.

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* See Professor Newberry's "Circles of Deposition," &c. Amer. Assoc. Proc., XXII., 1873, (2,) 185–196.

It is difficult to say what is here meant by "shallow water," for we know too little of the winds and currents of these old times. But the meaning of "near shore" can be estimated from the Catskill conglomerates, the coarsest of the entire series here seen from the Hudson River upwards, and therefore probably nearer their source than any of the other fragmental strata; and yet the crystalline rocks fróm which their pebbles have been chiefly derived cannot be less distant than the Highlands of the Hudson (forty miles), the same series of rocks in Connecticut and Massachusetts (forty), or the Adirondacks (sixty miles), for all the intervening areas, even if then exposed to erosion, were of non-crystalline rocks. "Near shore" does not, therefore, necessarily imply a very close neighborhood to land; and the carrying power of the paleozoic currents must have been very considerable. The identification of the source of the Catskill conglomerate pebbles is an interesting and important piece of work.

Folds and Faults. — The folds of small radius and varying form into which the above-described strata have been pressed, and the strong influence of the rocks' attitude on the surface form, combine to render this district an excellent training ground for Appalachian work. I know of no other where so many structural problems are as well shown within so limited a space. Two well-known features are clearly seen: the folds become more pronounced in going eastward, and all the anticlinals have their steeper dips on the west. Points of special interest may be named as follows.

The Catskill gorge from Austin's Mill up to Leeds gives a very fine series of natural sections. The railroad cutting and the lane leading up from the mill to the turnpike give good evidence of the conformity of the Hudson River strata under the limestones, and the Waterlime here presents two interesting forms of distortion. The first is an unconformity by horizontal faulting (fig. 3); the layers have been shoved past one another on an oblique crack. It is worth noting that a similar style of dislocation would probably be called true unconformity if it had taken place and been laid bare just at the junction of this formation with the Hudson strata below it; but happening twenty feet higher, it can be referred to its true cause. Secondly, we may note the effect of internal disturbance in the limestone, shown by the breaking up of some of its fine layers (fig. 16): this must be referred to the epoch of general folding, for examples can be found of all sizes up to a coarse brecciated mass several feet thick near the fault-unconformity; it is therefore an example of what Heim calls folding with fracture, as distinguished from folding by bending; and is explained by him as a folding that took place under a pressure of superincumbent rocks insufficient to cause plasticity in the brittle strata.* This fact may some day yield a measure of how many hundred or thousand feet of rock were *not* over the Waterlime when it was folded, and so lead to a conclusion respecting the former eastward extension of the Hamilton and Catskill sandstones.

Another conclusion may be noted: the strata showing these crowded layers lie near the axis of a synclinal trough, where it is often stated that folding produces tension, not compression. Scrope, for instance, compares folded strata to a bent board, which of course is stretched on its convex side.† Such a comparison is incorrect. None of the deep-lying rocks can escape compression during their folding: this can happen only to the superficial strata of the anticlinals. That synclinals are actually compressed, and not stretched, is shown by the growth of subordinate folds often found in their troughs; by the cleavage of slaty rocks at such points; and in general by the thickening of (argillaceous) strata at the turns and the thinning at the shanks or tangents of the folds, as was long ago pointed out by Sir James Hall,‡ and lately confirmed by Heim.§

Across the stream from the mill is a well-formed synclinal outlier (see Emmons, Pl. IV.) capped with Lower Pentamerus and perhaps with some Catskill Shaly limestone. Farther up the gorge, where the stream turns to the rock-strike, there are excellent exposures of Lower Pentamerus on the eastern (left) bank, and of Catskill Shaly opposite; the latter dips gently to the west at this point, but following it one third of a mile south, it becomes steeper, and at last is overthrown so as to dip 50° to the east. Above the next band, about at the middle of the west-east course of the stream, on the north bank, a distinct fault may be seen at the side of the railroad. The plane of the fault dips 45° east; on the western side, the Upper Pentamerus has a smooth, well-rubbed wall; on the east, the Catskill Shaly ends more unevenly, and supplies a quantity of fragments for the two feet of fault-breccia. There is no noticeable contortion of strata on either side. This example is interesting as it is a violation of the so-called "law of faults," (which I believe is no law at all,) for the upthrow overlies the hade. In this particular it confirms the hypothetical attitude of the fault-planes as generally drawn in Appalachian sections by Lesley and others, although these seldom if ever depend on direct observation. The example is further of use in showing that the fault may result from the same compressing force as the fold; and not from horizontal tension, such as is needed for the so-called normal fault. The throw here on the bank is probably fifty or seventy feet; it could be closely measured by more leisurely observation. We succeeded in finding the apparent continuation of the same fault half a mile to the north, but the intervening details of the map need revision. On the next turn of the stream by the railroad bridge, the upper limestones are finely shown on the east bank; on the other side, an obscure fold or fault complicates their succession. The grits and the thin Oriskany layer in the gorge at Leeds have already been mentioned.

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* Mechanismus der Gebirgsbildung, 1878, II. 31.

† Volcanos, pp. 51, note, 289.

‡ Edinb. Phil. Trans., VII., 1815, 97.

§ *Loc. cit.*, II. 48.

A cross-fault probably determined the gap on which the Kaaterskill turns eastward from the Marcellus at the saw-mill; for the folds do not correspond on the two sides of the gap, and the vertical limestones of West Berg seem displaced where they reappear on the north.

Other points of interest are as follows, beginning at the north end of the map: — Black Lake and a high hill next west of it; the hill is a saddle of grits on a limestone anticlinal; a rare occurrence. Canoe Pond and the steep plunge of the limestone under its eastern side. A Corniferous arch on either side of a little cross valley through which the railroad passes south of Leeds. The Quarry Hill synclinal and the Fuyk Valley anticlinal. The long tongue of Corniferous running down to Van Luven's Lake, and the large loose blocks of limestone at several points along it. The southern anticlinal valley, and the narrow faulted grit synclinals to the east of it. The way in which the several limestones wrap around the disappearing anticlinals is beautifully shown.

Surface Geology. — Glaciated rock surfaces are very seldom seen within the Little Mountain belt, but this is merely because the rocks are generally too weak to hold them. The firmer sandstones of the Hudson River group to the east show them abundantly, as on a large knob of rock alongside of the Mountain road in the village of Catskill just west of the stream; its steep northern slope gives a good small example of an overhanging polished surface. The only case of glacial action noted on the limestones was on the western side of the Corniferous anticlinal, where the Kaaterskill has recently cut away the protecting clays, just south of its cross valley by the saw-mill: these striae are very well preserved; they run horizontally along the steep limestone stratum, parallel to the valley. The Hamilton and Catskill sandstones west of our limestone belt preserve many and distinct scratched surfaces: the largest of these was found on a bare even bed of rock on the Mountain road at a four-corners, about half-way from the Marcellus valley to the foot of the long grade; they bear S. 20° W., and some are continuous for fifty feet. A little farther west the same direction is repeated, and with it there are many straggling scratches turning to S. 60° W. On the mountain road ascending to Beach's Mountain House, about half-way up its long grade, the scratches run S. 25° W., parallel to the mountain face. On the new road leading from the Kaaterskill Hotel eastward across the plateau to South Mountain, the freshly uncovered sandstone ledges show very distinct *Stossseiten*, indicating an ice-overflow from the Hudson valley across the mountain and up the Palenville clove; the directions of ice-motion, here clearly determined by the form of rock-surface and the well preserved scratches, were N. 80°, 75°, 50°, and even only 35° W., giving a westward deflection from the main valley of more than a quadrant.*

The general absence of drift over the limestone belt and the sandstones to the foot of the Catskills is noteworthy; largely on this absence depends the clearness of the topography of the region. There are no sheets or mounds of till or gravel; everywhere but in the deeper valleys the country rock comes close to the surface and appears in abundant outcrops; and the drift is recognized only in scattered stones and boulders of northern origin: in French's quarry there is, for example, a two-foot boulder of garnetiferous granite, presumably from the Adirondacks.

There is no clear evidence of any marked effect of glacial action on the topography, unless we place the little Black, Canoe, and Van Luven's lakes here; but they are small, and probably very shallow, and quite as likely the result of drift obstruction as of ice excavation: they all occur on the lower part of the grits, where these join the Upper Pentamerus, and this as we know elsewhere shows a tendency to valley form. We had not time to study the origin of the basin of Green Lake, the largest of the district.

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* This deflection has been observed by Mather, 1843, 203; Ramsay, Quart. Journ. Geol. Soc., XV., 1859, 208; and Julien, N. Y. Acad. Sci. Trans., 1881, 24–27.

The large blocks of Corniferous limestone, weathered loose along its margins, may be mentioned again here. The best examples are on the Old King's road where it joins the Mountain road; several of the blocks are eight or ten feet cube. They cannot be considered simply as glacial boulders, for they occur only along the disappearing margins of their formation; they cannot be of pre-glacial weathering, for the ice stream that filled the Hudson valley till it overflowed its mountain boundaries east and west can hardly have left any loose blocks so near where it found them. So we are forced to consider them largely the product of post-glacial weathering, mostly by solution; but this gives a so much greater measure of post-glacial erosion than is generally found, that it is not satisfactory. Some of the blocks are separated from one another and from the still continuous bed out of which they seem to have weathered, by a hundred feet or more. The limestone would therefore have to be easily dissolved by surface waters, although it is very dense physically; and yet the same limestone under the clays of the Marcellus valley, where much water must have filtered in along the contact of rock and clay, has not lost its glacial scratches. The case is not satisfactorily explained.

All the lower valleys are occupied by stratified clays capped with sands up to about one hundred and fifty feet above the Hudson (tide-water). Near the river, the area and often the depth of these clays are very great; they cover all but the higher sandstone ridges, which crop out as rocky islands. Farther back from the river, the clays fill the depressions among the limestones, as is nicely shown in the Fuyk, when viewed from the Lower Pentamerus cliff on the east; and the long valley cut on the Marcellus shale, where it is followed by the Kaaterskill and far north and south as well, is deeply buried under the clay terraces.

It is easy to see that, if the clays were stripped off, and the country elevated several hundred feet as it has been in the past, its valleys and drainage would be considerably changed from their present arrangement; but just what these changes would be is difficult to say. I think it probable, however, that the Kaaterskill would leave the Hamilton a little to one side of its present course at Big Falls; that both the Kaaterskill and the Catskill would run along the Marcellus valley at a lower level than their present beds, and would escape eastward by some channel farther south than our map extends. If this view is correct, it follows that Big Falls, like so many other cascades in New York and other glaciated States, result from an old stream's taking a new course (I believe this to be a general explanation for many falls); that the Kaaterskill now makes its way through the Little Mountains over a broadly open pass that once led from the Hudson to the Marcellus valley; that the Catskill, although larger than the Kaaterskill, was accidentally turned into a smaller cross-valley, which it has since deepened somewhat into the appearance of a gorge. Such disturbance of pre-glacial drainage is a very common occurrence in our Northern regions, and often gives rise to lakes.

Further study is needed to learn the features of the Helderberg folds as they extend northward to the south line of Albany County, where Mather (1843, 335) says they end, and to show their increase to the south.

Since writing my article for *Appalachia*, several months ago, an excursion to the mountains in Central Pennsylvania has given me new reason to repeat what was then said concerning the advantages of the Little Mountains for studying the elements of topography; for in Pennsylvania the structural features are on so much vaster a scale, that days are there required for what can be seen much more clearly in a few hours near Catskill.

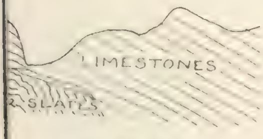
This article is accompanied by two plates, numbered XII. and XIII.

Plate XII. contains sixteen figures, described in the text.

Plate XIII. is a colored map showing the district here described.

CAMBRIDGE, January 15, 1883.

FIG. 6


LIMESTONES
SLATES

RONDOUT
opp WILBUR

FIG 7.

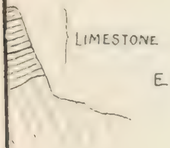

LIMESTONE
E

FIG 9 ESOPUS CR.

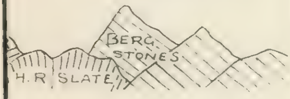

BERG
STONES
H.R SLATE

FIG. 10

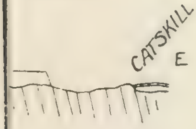
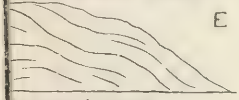


FIG 12

DSON RIVER GROUP



BELOW LEEDS

FIG.13.

S _ 1846.

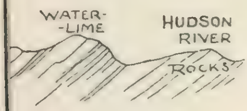
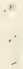

WATER-
-LIME
HUDSON
RIVER
ROCKS

FIG. I

EM

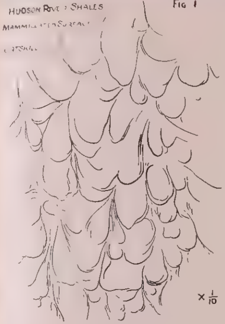
I



DA

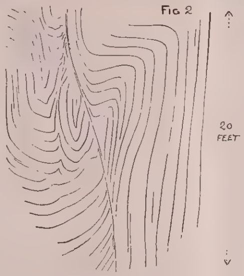
FRO

Fig 1


HUDSON RIVER SHALES
MAMMILLATED SURFACE
CATSKILL

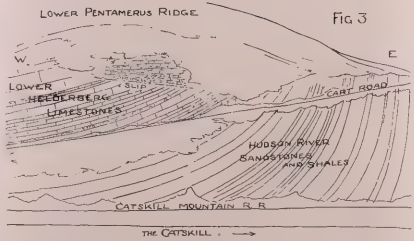
× 1/10

Fig 2



CONTORTED HUDSON RIVER SHALES
R.R. CUT, CATSKILL

Fig 3


LOWER PENTAMERUS RIDGE
W.
E
LOWER HELDERBERG LIMESTONES
SLIP
CART ROAD
HUDSON RIVER SANDSTONES AND SHALES
CATSKILL MOUNTAIN R.R.
THE CATSKILL →

SECTION BELOW AUSTIN'S MILL

Fig 4

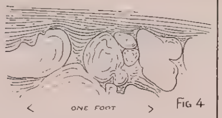
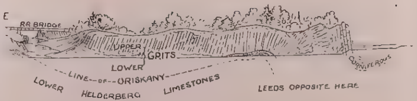
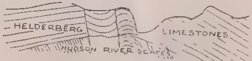


Fig 5.


E
RR BRIDGE
UPPER
GRITS
LOWER
LINE--OF--ORISKANY
LOWER HELDERBERG LIMESTONES
CORNIFEROUS
LEEDS OPPOSITE HERE

RIGHT BANK OF THE CATSKILL AT LEEDS

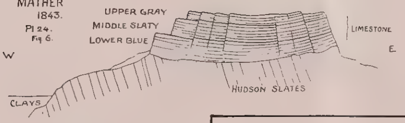
Fig 6


HELDERBERG
LIMESTONES
HUDSON RIVER SLATES

MATHER, 1843.
Pl. 26, fig 1.

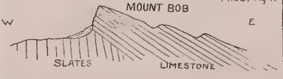
RONDOUT
OPP WILBUR

Fig. 7.


BECRAFT'S MOUNTAIN
UPPER GRAY
MIDDLE SLATY
LOWER BLUE
LIMESTONE
W
E
CLAYS
HUDSON SLATES

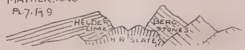
MATHER
1843.
Pl 24.
Fig 6.

Fig 8.


MOUNT BOB
W
E
SLATES
LIMESTONE

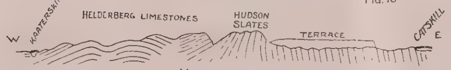
MATHER
Pl. 38, Fig 1.

Fig. 9


ESOPUS CR.
HELDER LIME
BERG STONES
H R SLATE

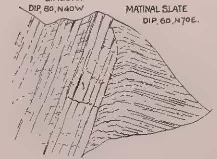
MATHER, 1843
Pl. 7, fig 9.

Fig. 10


W
KAATERSKILL
HELDERBERG LIMESTONES
HUDSON SLATES
TERRACE
CATSKILL
E

MATHER. 1843

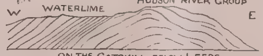
Fig. 11.


PRE-MERIDIAN LIMESTONE
DIP. 60, N40W
MATINAL SLATE
DIP. 60, N70E.

HASBRUCK'S QUARRY
RONDOUT, N.Y

H.D. ROGERS. - 1858. ii. 785

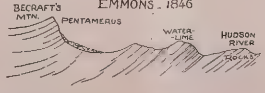
Fig 12


W
WATERLIME
HUDSON RIVER GROUP
E

EMMONS. 1846
Sec. 5. pl. xx.

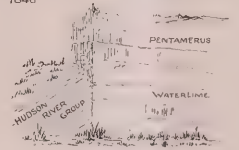
ON THE CATSKILL BELOW LEEDS

Fig 13


BECRAFT'S MTN.
PENTAMERUS
WATER-LIME
HUDSON RIVER ROCKS

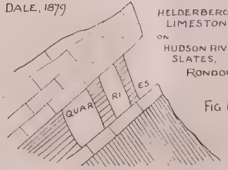
EMMONS. 1846

Fig. 14
EMMONS
1846


PENTAMERUS
WATERLIME
HUDSON RIVER GROUP

AT THE CEMENT QUARRIES
KINGSTON N.Y.

Fig 15



DALE, 1879

HELDERBERG
LIMESTONES
ON
HUDSON RIVER
SLATES,
RONDOUT

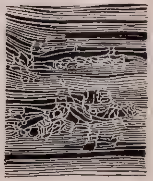
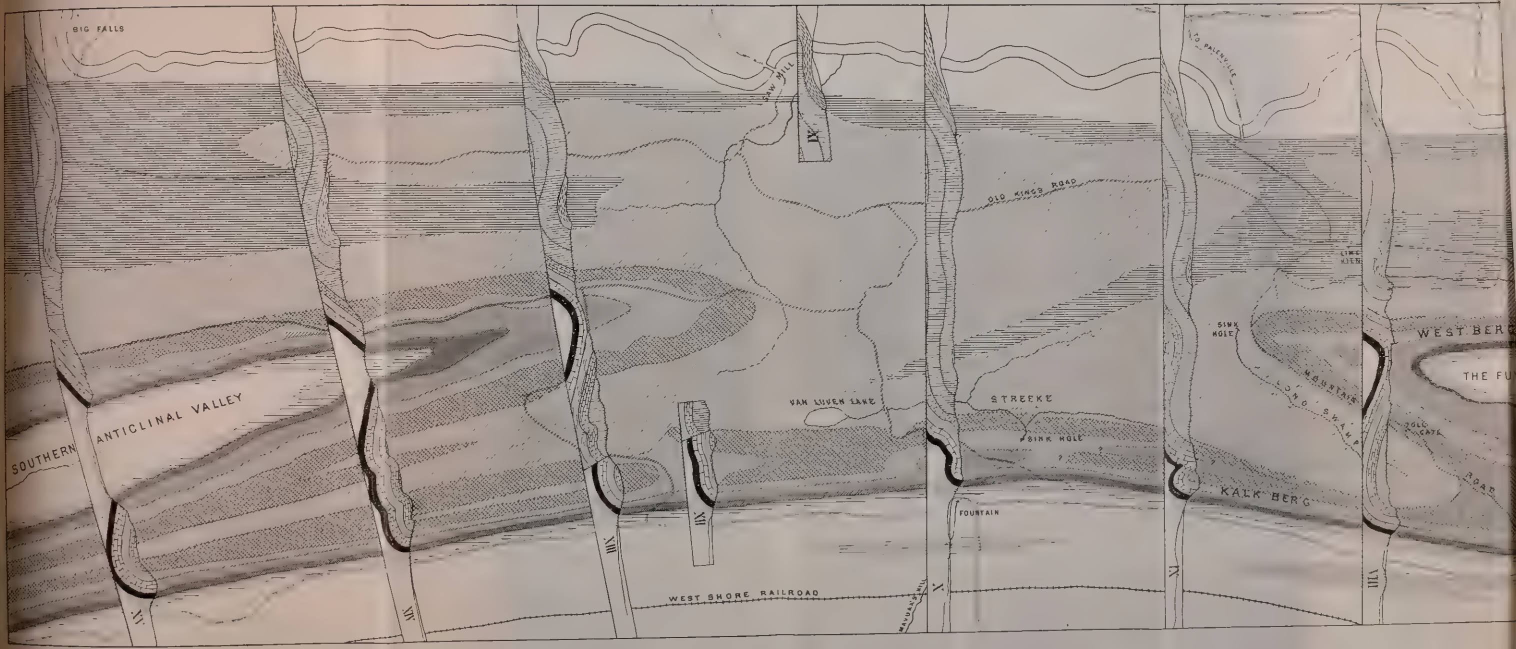
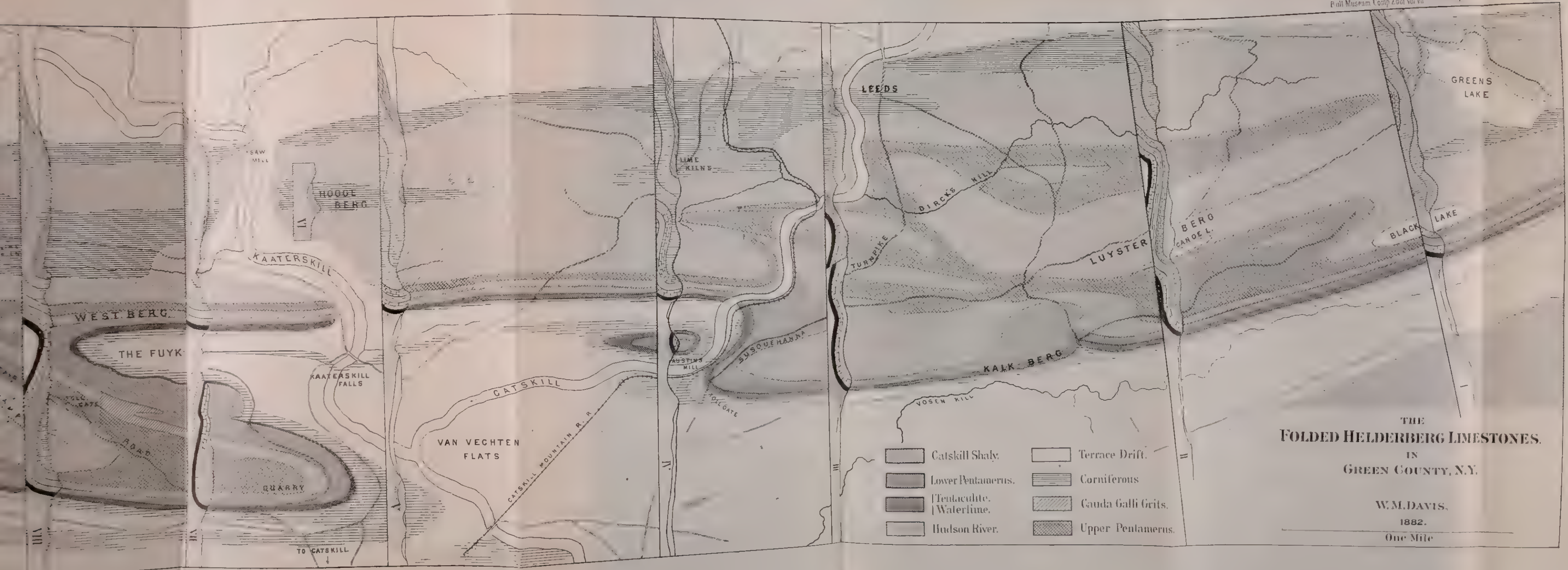


Fig 16

DIAGRAMS
OF
THE HELDERBERG ROCKS
IN AND NEAR
GREEN COUNTY, N.Y.
FROM VARIOUS AUTHORS & ORIGINAL DRAWINGS
BY
W. M DAVIS
1882

The Heliotype Printing Co. 211 Tremont St. Boston


BIG FALLS
SAW MILL
IX
TO PALENVILLE
OLD KINGS ROAD
LIME KILN
SINK HOLE
WEST BER
THE FU
MOUNTAIN
LONG SWAMP
TOLL GATE
ROAD
SOUTHERN ANTICLINAL VALLEY
VAN LUVEN LAKE
STREEKE
SINK HOLE
KALK BERG
FOUNTAIN
XV
XIV
XIII
XII
X
XI
VIII
WEST SHORE RAILROAD
MAVUAN'S HILL


GREENS LAKE
LEEDS
LIME KILNS
SAW MILL
HOOGE BERG
VI
DIRCKS HILL
TURNPIKE
LUYSTER
BERG
CANOE L.
BLACK LAKE
KAATERSKILL
WEST BERG
THE FUYK
KAATERSKILL FALLS
AUSTINS MILL
SUSQUEHANNA
KALK BERG
TOLL GATE
VOSEN KILL
CATSKILL
VAN VECHTEN FLATS
CATSKILL MOUNTAIN R. R.
ROAD
QUARRY
TO CATSKILL
VIII
VII
V
IV
III
II
I
Catskill Shaly.
Lower Pentamerus.
Tentaculite. Waterlime.
Hudson River.
Terrace Drift.
Corniferous.
Cauda Galli Grits.
Upper Pentamerus.
One Mile

THE
FOLDED HELDERBERG LIMESTONES.
IN
GREEN COUNTY, N.Y.

W.M.DAVIS.
1882.

BINDING SECT. MAY 16 1966

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